McNair Journal

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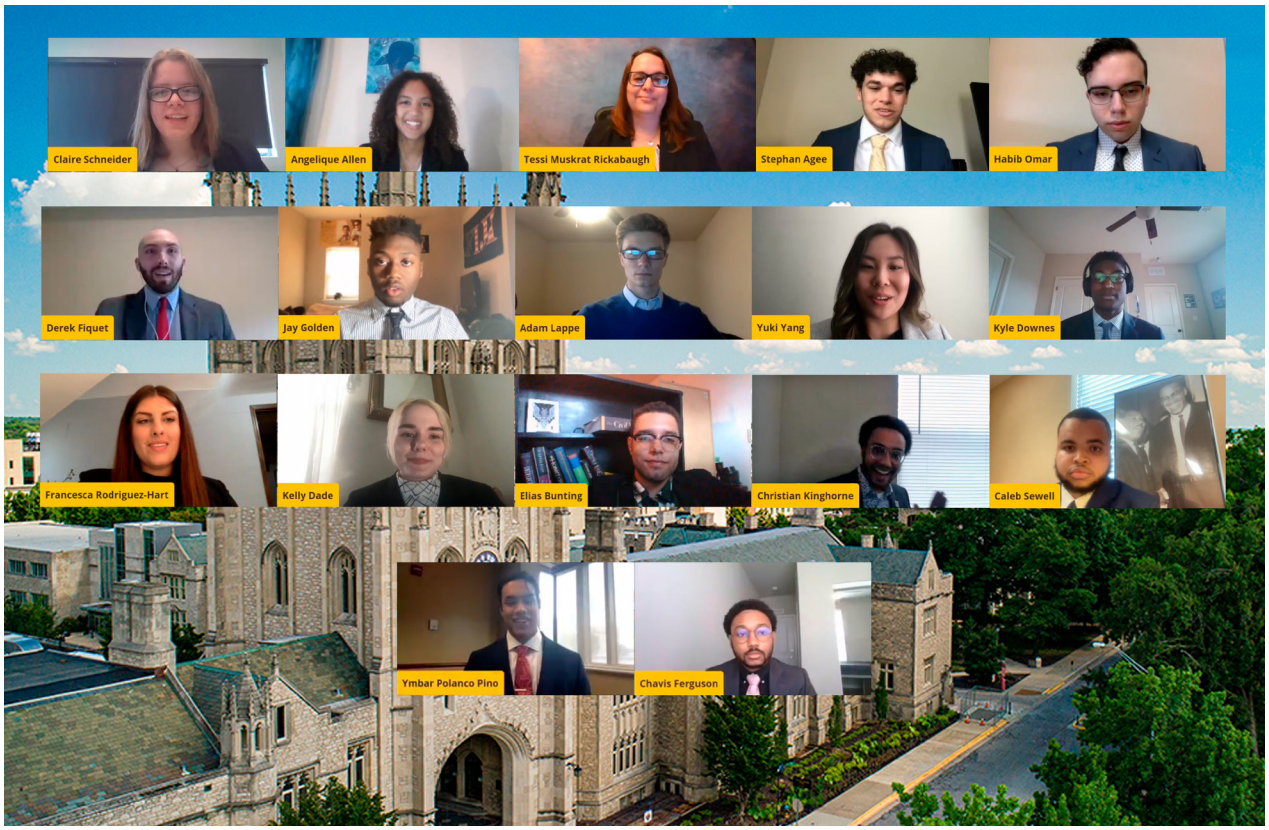

McNair Scholars Program

University of Missouri

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On the Cover:
McNair Scholars presenting virtually during the 32nd Annual McNair Scholars Conference.

MU McNair Journal

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Message from the Director

It is with great pride that I introduce this outstanding collection of articles from the 2020-2021 participants of the MU McNair Scholars Program. The papers presented here represent the culmination of a year's worth of research and scholarly activity. They reflect the energy, creativity and effort of the scholars, themselves as well as the careful guidance, support and diligence of their faculty mentors. Six very diverse topics are explored and reported in their entirety within this interdisciplinary journal. While their subject matter and journalistic styles may differ, they, along with the other McNair Scholars listed in this publication, are to be commended for their persistence and dedication to this rigorous undergraduate research experience that will benefit them greatly in their pursuits of graduate studies.

Since 1989, the McNair Program has been a University-wide effort that continues to attract students and faculty mentors from a variety of academic departments and fields of inquiry. Students have had the opportunity to learn about the importance of earning an advanced degree, while gaining the skills and tools that will guide them through their future academic journeys. The program proudly bears the name of astronaut and scientist, Dr. Ronald E. McNair, who died in the Challenger explosion in 1986. His accomplishments and high standards set an outstanding example for these developing scholars.

I am truly honored to be associated with an initiative such as this. So many faculty, staff and administrative members of the MU community have worked to ensure a supportive and cohesive environment that prepares these exceptional students for graduate programs. We are proud to highlight the work of these talented young researchers, in this, the twenty-fifth edition of the MU McNair Journal. Our best wishes go out to all of them as they continue to move along their scholastic continuum.

Natalie Downder, PhD
Associate Director, MU McNair Scholars Program

The McNair Scholars Program

BACKGROUND

College students who are conside ring study beyond the baccalaureate level realize their dreams through the McNair Scholars Program at the University of Missouri-Columbia (MU). MU was one of the original fourteen universities selected to develop a program established by the U.S. Department of Education and named for astronaut and Challenger crew member Ronald E. McNair. The purpose of the program is to provide enriching experiences that prepare eligible students for doctoral study.

PROGRAM ELEMENTS

One of the most exciting aspects of the McNair Scholars Program is the opportunity for junior or senior undergraduate students to participate in research experiences. McNair Scholars receive stipends to conduct research and engage in other scholarly activities with faculty mentors from the areas in which they hope to pursue graduate study. These research internships are either for the academic year or for the summer session and are under the supervision of faculty mentors. For academic year internships, students work a minimum of ten hours per week during the fall and winter semesters. Summer interns work full-time for ten weeks.

McNair Scholars also attend professional conferences with their mentors, go to graduate school fairs, prepare for graduate school entrance exams, receive guidance through the graduate school application process and obtain information on securing fellowships, graduate assistantships, and loans. Participants learn about graduate school life, advanced library skills, and effective ways to present their work. At the completion of the research internships at MU, McNair Scholars make formal presentations of their research to faculty and peers at the McNair Scholars Conference and submit papers summarizing their work. Students who participated as juniors the previous year continue in the program during their senior year for graduate school placement and to further develop their skills.

ELIGIBILITY

Participants must meet grade point average standards; be U.S. citizens or permanent residents; and qualify as either a first generation college student with an income level established by the U.S. Department of Education, or a member of a group that is underrepresented in graduate education.

All students who wish to be involved submit an application to the program. A committee composed of faculty members and representatives from both the graduate dean's office and the McNair Scholars Program selects participants and approves faculty mentors. Research internships are offered to those students who are juniors or seniors and are identified as having the greatest potential for pursuing doctoral studies.

Assessment of genetic variation for economic traits among eastern black walnut (*Juglans nigra*) cultivars

ELIAS BUNTING
Ron Revord, J. Bryan Webber, Nicholas Meier, and Mark Coggeshall

Ron Revord, PhD, Mentor
Center for Agroforestry

Elias Bunting is junior from Jackson, Tennessee. Elias' research interest is in improving the biotic and abiotic stress resistance of tree and crop species through studying the underlying genetic mechanisms associated with such traits. Specifically, he is interested in mitigating adverse conditions for tree and crop species through calculating genetic linkage maps of particular traits, screening for disease and drought resistance, and the application of machine learning.

This fall he is currently applying to graduate programs in forestry.

Eastern black walnut (*Juglans nigra*) is endemic to the eastern US and highly prized for its valuable timber and uniquely flavored nuts. The University of Missouri houses the largest black walnut germplasm repository at the Horticulture and Agroforestry Research Center in New Franklin, MO. Cultivars in this repository support an improvement program focused on economic traits related to nut production (nutmeat mass, overall nut quality, precociousness, and yield). In 1996, two to four ramets of 67 cultivars were grafted and established in a for further evaluation. Beginning in 2001, through 2015, the collection was evaluated for 11phenological and 10 nut quality and yield characteristics. Economically relevant traits demonstrate considerable variation, including nut weight, percent kernel, and precociousness (total nuts produced age 6 to 10) ranging from8.8 to 43.0 g, 5.3 to 39.3 percent, and 16 to 1522 total nuts, respectively. Nut weight and percent kernel were negatively correlated (r=-0.60), while precociousness correlated positively (r= 0.38) with percent kernel and negatively (r=-0.32) with nut weight. Precociousness also correlated negatively with first (r= -0.39) pistillate emergence date. Overall, trait correlations demonstrate promise for improving black walnut for nut production despite multivariate selection criteria. Principal components analysis demonstrates genetic variation at the level of the individual, with weak cultivar clustering. The first and second principal components explain a total of 49.2% data set variation. Eigenvector loadings are driven by nut weight in principal component one and nut length in principal component two. Insights gained from the principal component analysis inform the selection of complimentary breeding parents, helping to reduce complexity in multivariate selection criteria.

Introduction

Eastern black walnut (*Juglans nigra L.*) is one of 21 species within *Juglans* and a member of the subsection *Rhysocaryon* (Manning 1978). It is the most economically valuable hardwood timber species in North America (Miller and Chamber 2013, Walker et al. 2002, Reid et al., 2009), and Missouri is home to the largest standing number of eastern black walnut trees. Most eastern black walnut nuts harvested commercially are derived from unimproved (wild) sources. This supply from wild trees is highly variable from year to year in terms of yield and quality. Missouri's crop ranges from 12 to 16 million pounds (about 65% of the total supply

in the U.S.) and creates approximately $2.6 to $3.5 million in revenue for harvesters annually (Hammons Products Co., personal communications). Nuts harvested from wild trees also garner a low price of $0.16/lb. hulled due to their low kernel percentage (6-14%) and mixed quality, with many nuts having a dark color and acrid floral/fermented aroma and flavor. Recently, however, there has been an increased demand for nuts harvested from grafted cultivars withgenetically improved nuts (Thomas and Prindle 2016). Improved selections with >30% kernel and other preferred attributes are purchased at around $0.75/lb. hulled wholesale by Hammons Products Company (Stockton, MO), with ~2,000 acres of orchards producing an equivalent value to growers as the current production levels based on nuts harvested from wild trees (Hammons Products Co., personal communication). Improved selections are attractive to commercial growers and consumers as they provide consistent production of nuts with desirable traits.

1.2 UMCA Breeding program

The University of Missouri Center for Agroforestry (UMCA) has curated and maintained a collection of over 60 high kernel percentage cultivars of *J. nigra* since 1996 (Coggeshall and Woeste 2010). Cultivars from this collection (with kernel percentages in the upper 20s) were used to initiate the first organized genetic improvement program for nut/kernel producing *J. nigra* beginning in 2001 (Coggeshall 2002). Historical evaluations of this collection revealed a wide range of desirable traits that contribute to overall yield efficiency (kernel weight, percentage, and color, precocity, spur-bearing habit, anthracnose tolerance, flowering time, and season length) are present across the repository (Coggeshall 2011). If utilized systematically, this repository could be leveraged for use as breeding parents to recombine desired traits into improved cultivars.

The main traits of interest (kernel weight and percentage) are valuable to consumers of nut products, but equally important traits such as precocity, spur-bearing habit, alternate bearing, and disease resistance will impact the overall yield of the crop. Black walnuts are long lived trees but often do not begin producing until 10 plus years after planting (Reid and Coggeshall et al. 2009). Precocity in black walnut will speed up the time growers have to wait for their return on investment in new orchards. Spur-bearing habit on black walnut refers to short, compact branches that arise along primary limbs that each produce a fruiting cluster, over multiple years. Cultivars with this fruiting habit are the most productive (Reid et al 2009). Alternate bearing can lead to heavy crop loads one year but will typically impact the succeeding year's crop by reducing the amount of available nutrients for the tree, decreasing flower initiation and/or early nut development. Therefore, selection criteria related to production, as they pertain to year-to-year stability, are more important than the highest production in a single year. Common black walnut diseases such as thousand cankers disease (Blood et al. 2018) can hamper all biological processes, costing commercial growers significant lost revenue each year (Treiman & Tuttle 2009). Because nut production is so heavily tied to tree physiology, breeders must find ways to optimize traits that impact branching habit, flowering time, photosynthetic rates, disease resistance, and efficient nutrient allocation to improve/stabilize production (Rink 2017). A strategy that has been used in other breeding programs to leverage breeding parents to optimize offspring development is termed morphological characterization.

Morphological characterization has helped breeders organize candidate germplasm to initiate breeding programs (as reviewed in Bernard et al. 2017). Morphological traits such as nut dimensions and bearing habit are influenced by genetic (G), environment (E), and the interaction of this G x E affect (Bernard et al. 2017). Understanding the phenotypic variation associated with these morphological traits can expedite germplasm development in breeding programs using selections from wild populations (Ghasemi et al. 2012). Breeding programs in Iran found promising genotypes in *J. regia* that were selected based on phenological and pomological trait, including leafing time, spur-bearing habit, and flower morphologies (Ebrahimi et al 2011), bud break (Arzani et al. 2008), spring frost tolerance (Mahmoodi et al. 2016), and nut yield, nut characteristics, and kernel quality (Arzani et al. 2008). Strong relationships have also been found in *J. regia* between nut weight and nut length, nut weight and nut width, and kernel weight and nut diameter (Bujduso et al. 2021, Arzani et al. 2008).

Similar studies have been performed in *J. regia* throughout Europe including Turkey, Albania, and Serbia, where superior cultivars were selected for variability in nut characteristics, improved yields, and cold tolerance as well as late flowering, walnut blight, and anthracnose tolerance (Bayazit 2012; Aslantas 2006; Zeneli et al. 2005; Miletic et al. 2003). In France, a study on 2450 hybrids from 22 crosses of French germplasm and varieties from California found a correlation between leafing date in 1-year-old trees and leafing date in the same trees years later, showing that early screening of this trait is possible (Germain 1990). By a thorough characterization of morphologies within a germplasm repository, researchers can identify unique recombinant, complimentary breeding parents, and traits correlations that can frame crossing schemes and impact the long-term success of breeding operations.

1.3 Objectives

This study performs characterization of the morphologies on historical data from the UMCA's *J. nigra* germplasm repository. The goals of this morphological characterization were to 1) format historic raw data files for subsequent analysis, 2) perform correlations, analysis of variance, and

principal component analysis, and 3) gain insight on how genetic diversity for traits of interest is distributed across the germplasm collection. Our analysis will provide insight into improving black walnut for multiple characteristics – specifically the morphological characteristics of nut dimensions and percent kernel as well as late leafing dates (bud break dates) and early harvest. As has been found in Persian walnut (*Juglans regia*), improving these traits will reduce late frost damage and improve overall harvest quality (Marrano et al. 2019).

2. Methods and Materials

2.1 Plant material

The 65 cultivars representing a wide range of phenotypic diversity were grafted with at least 4 ramets per cultivar throughout three repositories at the Horticulture and Agroforestry Research Center (HARC), in New Franklin, MO (39°01′N, 92°74′W). The identity of the cultivars in this population was verified using DNA fingerprinting and microsatellite SSR markers (Zhao et al. 2017). The trees were planted at 40 x 40 foot spacing and were pruned and fertilized annually with the best management practices applied during their establishment.

2.2 Evaluation methods

Beginning in 2001, all cultivar ramets in these repositories were evaluated for seven morphological traits including: date of bud break, first pistillate date, last pistillate date, first pollen shedding date, last pollen shedding date, harvest date, and length of the season measured from the number of days from the date of first pistil emergence to harvest date. Additionally, each year the number of nuts produced by each tree and the alternate bearing index were calculated. These traits were evaluated in this germplasm repository from 2001 to 2008.

As the trees began producing nuts, additional phenotypic data for nut and kernel quality was collected from the germplasm for years 2007, 2008, 2009, 2010, 2013 and 2015. During these evaluations, 2 replications of 25 nuts were randomly selected from the total yield. Each nut was measured (mm) for its length, width, and depth. Each in- shell nut was weighed (g) before the nut was cracked and the kernel nutmeats meticulously extracted from the nutshell and weighted. The nutmeats and in-shell mass were used to calculate the kernel percentage for each nut. Kernel color was also evaluated using a 1 to 5 rating scale with 1 being lightest and 5 being darkest. The values fromthe 2 x 25 nut samples for each cultivar were averaged for analysis.

2.3 Statistical analysis

In 2021, the raw data that had been collected from the black walnut germplasm repository was compiled into usable data sheets for analysis. Statistical analysis began by creating histograms to check for the distribution and normality of the datasets, Pearson's correlation matrices, followed by one-way analysis of variance, and Tukey's test of honest significant difference. Multivariate statistics were performed using principal component analysis and biplots to visualize the distribution. All analyses were perform using the software version R studio v. 1.4.1106. The R-packages used for data wrangling, data analysis, and generating graphics included: ade4 (v1.7-16; Dray & Dufour 2007), factoextra (v1.7; Kassambra & Mundt 2020), magrittr (v2.0.1; Bache & Wickham 2020), textshape (v1.7.1; Rinker et al. 2020), ggplot2 (v3.3.3; Wickham 2016), and dplyr (v1.0.5; Wickham et al. 2021).

3. Results and Discussion

3.1 Summary statistics

Summary statistics for phenological and nut quality characteristics are displayed on (Table 1). Frequency distributions for kernel color, kernel venation, percent overlap and nut weight were all skewed left while last pistil, first pollen and last pollen were skewed right. Kernel Suture width, (suture), kernel width (cheek to cheek), and nut length had normal distributions with percent kernel, first pistillate date, bud break date and harvest date presenting irregular distributions about the mean. Data was normalized using a how box test.

Historically, black walnut cultivars have been produced in abundance, resulting in large variation in leafing date, nut production, and optimal harvest (Reid et al. 2004). The UMCA germplasm consists of wild selections with superior attributes in these specific traits. Our results show that trait variation was maintained as wild selections were propagated and used as cultivars. Phenological data such as bud break, first and last pistillate, pollen dates, and percent overlap fell between the months of April to June. Bud break ranged from April 8th until May 19th.Pollination occurred as early as April 19th and as late as June 6th. Nuts were harvested from September 4th to October 16th with an overall season length of at least 97 days to at most 175 days. Nut and kernel dimensions displayed a wide range, with kernel weight as the nut character with the highest variation at 23.14% coefficient of variation (CV). Bud break dates had a CV of 42.55%, while pollen shed first and last pollen shed occurs over a narrower range, respectively. Taken together, ample genetic variation exists in the cultivar collection for improvement.

Table 1. Descriptive statistics of eastern black walnut (*Juglans nigra*) phenological and kernel morphological traits of studied genotypes

Trait	Unit	Min	Max	Mean	SD	CV%
Bud Break	Date	8-Apr	19-May	-	-	-
First Pistillate	Date	17-Ap	28-May	-	-	-
Last Pistillate	Date	28-Apr	8-Jun	-	-	-
First Pollen	Date	19-Apr	31-May	-	-	-
Last Pollen	Date	25-Apr	6-Jun	-	-	-
First Overlap	Date	24-Apr	9-Jun	-	-	-
Percent Overlap	%	0.00	2.50	0.26	0.20	86.90
Flower Type	Dichogamy	1	2	-	-	-
Season Length	Days	97.00	175.00	136.50	14.20	10.40
Alternate Bearing Index	-	0.25	1.00	0.60	0.10	26.20
Kernel Length	mm	27.00	63.00	38.20	4.00	10.50
Kernel Width (Suture)	mm	19.50	40.30	29.80	2.40	8.00
Kernel Width (Cheek)	mm	25.90	50.40	38.00	3.90	10.20
Nut Weight	g	8.80	43.00	19.50	4.20	21.50
Kernel Weight	g	1.00	8.60	5.30	1.20	23.10
Percent Kernel	%	5.20	39.20	26.80	5.90	22.00
Total Nuts (2002-2006)	No.	16	1522	421	354	84
Kernel Color	Categorical	1.00	4.20	1.80	0.70	37.40
Kernel Ventation	Categorical	0.00	3.50	1.40	0.60	40.40

3.2 Pearson Correlation

Pearson correlation values are reported in (Table 2). Significant correlations, ($p < 0.01$) or ($p < 0.05$) are indicated. Importantly, nut weight was strongly correlated with nut width suture to suture, nut length, nut width cheek to cheek, and weakly correlated with kernel weight at (r= 0.92), (r= 0.63), (r= 0.88), and (r= 0.27), respectively. Interestingly, nut weight has a notable negative correlation with kernel percentage (r= -0.6). Nut suture width and cheek width were also negatively correlated with percent kernel; (r = -0.58) and (r= -0.53). Bud break was only significantly correlated with first pistillate (r= 0.48). Harvest date was correlated with nut length (r= 0.39) nut weight (r= 0.4) and nut width suture to suture (r= 0.41) but the relations with nut width cheek to cheek (r= 0.29). and percent kernel (r= -0.22) were weaker. Kernel weight was weakly correlated with nut width suture to suture (r= 0.24) as well as nut width cheek to cheek (r= 0.37). Kernel weight was positively correlated with percent kernel (r= 0.51). Harvest date was weakly positively correlated with bud break at (r= 0.33).

These data suggest that, considering this germplasm, kernel weight and nut weight will be difficult to increase simultaneously, and increasing percent kernel percentage might not be achieved by selecting higher overall nut mass. Instead, selection emphasis to improve kernel percentage might be better placed on kernel mass, or secondary characters that have a strong positive with both kernel mass and kernel percentage. Smaller nut dimensions predict a larger percent kernel. Phenological traits of interest, late bud break and early harvest date, show a weak positive relationship and potential for simultaneous improvement. These phenologies also appear uncorrelated with nut and kernel quality characters, and therefore, our data supports the potential for cultivar improvement with early bud break, early harvest date, and overall nut quality.

Table 2 Pearson Correlation Matrix of 10 of the phenology and kernel quality traits of the No. of studied Black Walnut genotypes (*Juglans nigra*)

	Bud Break	First Pistillate	**Harvest Date**	**Nut Length**	**Nut Width (suture)**	**Nut Width (Cheek)**	**Nut Weight**	**Kernel Weight**	Percent Kernel	Total # Nuts 2002-2006
Bud Break	1	-	-	-	-	-	-	-	-	-
First Pistillate	**0.48****	1	-	-	-	-	-	-	-	-
Harvest Date	**0.33**	0.23	1	-	-	-	-	-	-	-
Nut Length	0.03	0.03	**0.39****	1	-	-	-	-	-	-
Nut Width (Suture)	-0.08	-0.01	**0.41****	0.62**	1	-	-	-	-	-
Nut Width (Cheek)	0.15	-0.20	**0.29***	0.34**	**0.82****	1	-	-	-	-
Nut Weight	0.10	-0.12	**0.4****	**0.63****	**0.92****	**0.88**	1	-	-	-
Kernel Weight	0.05	-0.04	0.24	0.21	**0.24***	**0.37****	**0.27***	1	-	-
Percent Kernel	0.07	0.10	**-0.22**	-0.19	**-0.58****	**-0.53****	**-0.6****	**0.51****	1	-
Total # Nuts 2002-2006	0.21	-0.39**	-0.27	0.05	-0.25	-0.32*	-0.32	0.03	0.38**	1

* Denotes significance at the 0.05 level. ** Denotes significance at the 0.01 level

3.3 Principal Components Analysis

PCA was conducted to show how genetic variation for traits of interest is partitioned amongst the cultivars. Principal Component (PC) 1 accounts for 24.1% of the total variation in the dataset while component 2 accounts for 19.3%. Across these two dimensions, the accessions displayed an even distribution (Fig 1), indicative of variation most explained at the level of the individual. Quadrants 1, 2, 3, and 4 account for 21.45%, 29.93%, 24.39%, and 24.39% of the accessions, respectively. Some spatially distant outliers were observed like 'Cooksey' and 'Cochrane', who have quite a small nut with exceedingly high kernel percentage and were removed from the dataset to better capture trends amongst the remaining cultivars. Table 3 displays the eigenvalues of PC1 and PC2. These values explain degree and directionality in which respective traits explain variation in the PCs and the spatial distribution associated with the eigenvectors. Nut weight and nut width (suture) held the highest loadings in PC1,0.28 and 0.27, respectively. Precociousness and kernel percentage showed to strongest opposing directionality, -0.16 and -0.18, respectively. Nut length, kernel weight, and kernel percentage displayed similar positive loadings in PC2 (0.22 - 0.29), along with quality characters color and venation (0.22 and 0.29). The directionality and loadings of PCA eigenvectors (Figure 2) suggest nut length might be an appropriate indirect selection parameter of breeding parents and offspring for improving kernel weight and percentage simultaneously.

Table 3 Eigenvalues illustrating the numerical explanations of the spatial separation of the components.

Primary component	**PC1**	**PC2**
Percent kernel	-0.18	0.22
Kernel weight	0.12	0.26
Precociousness	-0.16	0.12
Width (Suture)	0.27	-0.01
Nut Weight	0.28	0.00
Nut Length	0.12	0.29
Color	-0.04	0.22
Venations	-0.04	0.29
Alternate Bearing Index	-0.05	0.13
Bud Break	0.11	0.16
Flower Type	0.05	-0.01
Harvest Date	0.20	0.05
Season Length	0.12	-0.06
Eigenvalue	0.12	0.26
Variance Percentage	-0.16	0.12
Cumulative Variance Percent	0.27	-0.01

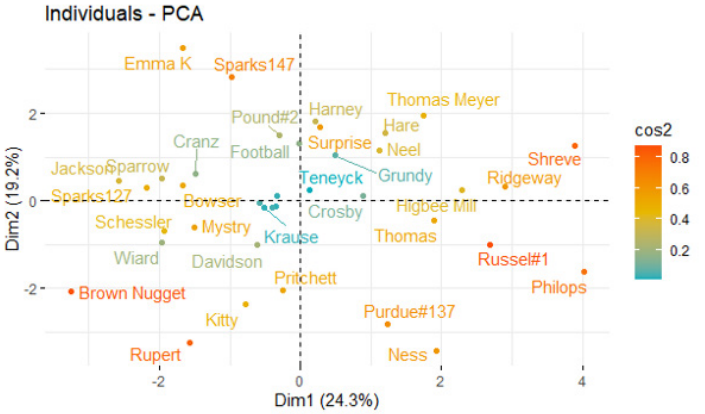

Figure 1. Representing the extent of the relationships between the accessions. Cos2 values delineate the strength of the relationship

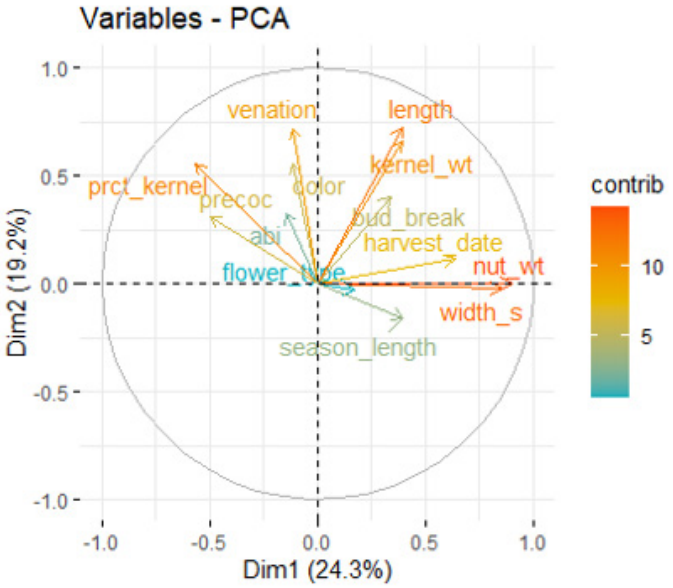

Figure 2. Depicting the vairables as vectors. Orthogonal relationships distinct loading while opposing directionality would indicate an inverse relationship. The degree of contribution refers to how much variation in the dataset each variable contributes to.

The loading of specific cultivars with the eigenvectors informs use as breeding parents for multivariate criteria. 'Pound #2' and 'Football' load with color, venation, and ABI. 'Cranz', 'Bowser', 'Tomboy', 'Sparks 127', and 'Jackson' all load with precociousness and kernel percentage. The extent of these loadings is described by the Cos2 values. Positive separation along PC 2 is characterized by 'Daniel', 'Hare', 'Thomas Meyer', 'Neel' and 'Harney' and their loading with nut length, kernel weight, and budbreak. Separation of 'Teneyck', 'Crosby', 'Higbee Mill', and 'Ridgeway' also load positively with harvest date, and nut weight. The vector directionality described here provides insight on how traits are partitioned across the collection. Vectors loading in opposition explains characters with contrasting relationships. Precociousness and season length were almost directly linearly opposed – most all

precocious cultivars have a long season length. In Figure 2, orthogonal relationships between eigenvectors indicate that independent variation explains each trait. Orthogonal vectors are kernel weight/nut length and kernel percentage/ precociousness. Cultivars along these vectors could be selected for recombining these respective traits into breeding progeny.

4. Conclusions

This evaluation of black walnut cultivars is the largest of its kind. The amount of variation in the germplasm lends itself well to multivariate analysis and breeding. The conclusions of this project add to the literature on approaches to selective breeding in the species and support the continued genetic improvement of black walnut for nut/ kernel production. Nut length may provide an important parameter for indirect selection of breeding parents and progeny with both high kernel percentage and kernel mass, as we report that direction direct selection on kernel percentage in progeny descending from some cultivars might lead to decreased nut weight. Multiple additional insight can be discerned by comparing eigenvector loadings and directionality that will inform how breeding programs structure crossing schemes and select parentage.

Acknowledgements

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After the Lawns are Gone:
Mending a Gap Between Theory and Practice

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Abstract

With climate change and the harmful effects of herbicides and pesticides, grass lawns will no longer be a viable option for homeowners. Research has shown that there are numerous sustainable alternatives, yet these alternatives are gaining little to no traction in the marketplace. Trying to mend a gap between theory and practice is important to understand what homeowners need so that they will make the change. It is with this research project to understand from a homeowner's perspective to find a sustainable alternative that homeowners would readily transition too. Using a comparative method traditionally used in product development, homeowners compared images of different sustainable lawn alternatives and chose which solution would best fit their wants and needs. The data was gathered using an online survey site, Qualtrics. Neighborhood association leaders were contacted and encouraged to participate in this study. The data was analyzed through an excel spreadsheet that contained all the homeowner's responses to both the comparisons and to the short answer responses. The findings were optimistic and suggested that homeowners would be willing to make the sustainable transition. Many homeowners would prefer to switch to native plantings, though there was some concern expressed that homeowners were unsure about how to care for these new alternatives. Based upon the results, it shows that homeowners would be willing and are enthusiastic about transitioning, but more work needs to be done to make sure that there are resources for homeowners so that alternatives would be as easy to implement into their yards as grass lawns are now.

Introduction

Origin of the American Lawn and its influence on the American Dream: From coast to coast across America, from the forest to the desert one thing that unites homeowners, the ubiquitous grass lawn. In early America settlements land adjacent to homes was used for growing food and raising animals including chickens and pigs (Chapman. W. 2000 p.3). The green grass lawn was promoted by Landscape Architect Fredrick Olmsted in the late 1880s and feature prominently in the design of the suburban estates of the upper class. After WWII, the lawn spread to middle class American households though the development of new tract housing developments, such as Levittown (Penick, P. 2013 p.1). The grass lawn thus became an integral feature how people defined the American dream of home ownership. Over the years that followed, grass lawns spread across the continent

becoming the new normal and our nation's most cultivated crop, even though it originated as an invasive species.

Gordon has argued that lawns benefit communities by creating the impression that we all live together, in one class, in a single park (Chapman, W. 2013). The perception that lawns reinforce a sense of community identity may explain why the traditional grass lawn has endured for decades. However, this sea of green also has significant drawbacks. In 2011, there were over 58 million lawns across the United States; homeowners are spending an average of 30 billion on lawn care every year (Hogan, C. 2011). Lawns use more herbicides, pesticides, fertilizers, and water than any other crop grown in America (Chapman, W. 2013). These harmful chemicals eventually make their way to water sources, not only causing harmful effects on the environment but also for animals and people.

Continuing to consume water at alarming levels to tend a vast ornamental carpet of green, may soon become a price to great to pay. A range of workable alternatives have been developed, and yet these are gaining little or no traction in the marketplace. Switching to sustainable alternatives for lawns will only matter if this becomes a new norm appreciated as a better way to design our residential landscapes. Sustainable alternatives reduce herbicide and pesticide use, while encouraging diversified plant life to create a better habitat for wildlife and homeowners. Finding a New Tradition: A new tradition is needed to replace the lawns that stretch across American. Research has shown the benefits of switching to a sustainable lawn alternative. Researchers have found various techniques that could be implemented by homeowners such as:

1. using native plants,
2. intertwining the green space with gravel or rock pavers,
3. planting more trees
4. using alternative ground covers.

This study is working to understand why more homeowners are not transitioning to the alternative lawns, whether it is a personal preference or city regulations, which restrict the type of residential outdoor space allowed. With the knowledge generated by this study, one can understand the changes required to result in fewer lawns, and this could help to understand the gap between research and application. The insight gained from this study can establish a better understanding of solutions that could influence future research and designs that impact the influence of the more sustainable lawn alternatives. Acquiring insight as to what are the factors that are contributing to the gap between research and applications is the focus of this study.

Literature Review

The goal of this literary review to look at current research methods in the landscape architecture field, sustainability aspects that should be applied, lawn care trends and transitions, and the history of the lawn in America.

Research Methods: The diversity of the problems encompasses social, cultural and environmental issues which are best understood through in depth conversations. "To understand the sociocultural drivers of land-use decision-making and management practices in neighborhoods surrounding the two study sites, we engaged with 120 participants via semistructured in-depth interviews, focus groups targeting groups of neighbors, and workshops over a three-year period" (Burr et al 2018). The Covid-19 pandemic made in person interviews with residential homeowners difficult and to reach a large number of people safely, the next best alternative was to have the participants complete an online survey. This is also a very successful option for conducting research. When questioning homeowners about sustainability strategies a method that has been used is to have a comparison where the survey participants choose between two different options.

Sustainability for Lawns: Grass lawns are usually a feature correlated with urban greenspace, especially in the United States. "Species poor and intensively managed, lawns are ecologically impoverished, however environmentally aware lawn owners are reluctant to implement alternatives due to aesthetic concerns. Developing an alternative lawn format which is both biodiversity friendly and aesthetically pleasing is an imperative for urban greening" (Conrad, S. 2019).

Lawn Care and Alternatives: Residential lawns create a uniting force between neighbors and this unity makes the neighborhoods feel safer to residents. "Where the use of lawn alternatives has been investigated (primarily in North America), alternatives are not found to be widely adopted, and there is little correlation between a lawn owners' choice of alternatives and their environmental motivations; alternatives tend to be implemented on the basis of aesthetic improvement. This is in large part due to cultural norms found in North America where the lawn has particular symbolic value" (Smith, L. S., 2014). This social aspect could influence the reason why sustainable alternatives are not being adopted for residential lawns. Interviews from homeowners revealed that "front yardscapes became contested spaces when residents departed from perfect-lawn norms. By planting natives, mowing less frequently, and removing turfgrass, participants acknowledged they were challenging norms that represent neighborhood aesthetics, norms, values, and cultural identity. They described the resulting tensions and conflicts with other residents that ranged from indirect confrontation (spraying weed killers along property lines) to direct feedback and pressure ("mow your yard!") to formal weed ordinance violation complaints." (Burr et al 2018).

History of the Lawn: As time goes on, designs in architecture and every other aspect of our life changes, or modifies but the lawn has continued to be the pinocle of the American society. "The notion of a front lawn began to take shape at the end of the eighteenth century, borrowed by a few wealthy Americans from French and English aristocratic landscape architecture" (Jenkins, pg 3). After WW2, with

the growth of suburbia, lawns became more prominent in residential use to the point of becoming a cultural standard. "In many communities there is enormous peer pressure to have a good lawn. The definition of a "good" lawn has evolved to mean a plot with a single type of grass with no intruding weeds, kept mown at a height of an inch and a half, uniformly green, and neatly edged. A multibillion-dollar lawn industry has developed in the United States, unlike any other country in the world" (Jenkens, pg.5). Lawns have been an important part of American history and they have been a part of our culture and social norm, but these lawns do not express the geographical differences or the native plant heritage of the regions across the United States instead lawns oppress the native with the continuing green from an invasive plant.

Methods

Participants: The target group for this research is single family homeowners in the Columbia area. After considering several locations in central Missouri, the city of Columbia was the decided upon testing area. Choosing to conduct the research in Columbia provides the opportunity for more participants who live in the suburbs with larger grass lawns. Reaching Out to Participants: To find participants, the process started with searching through Columbia city website in the planning and neighborhood associations section, this page provided a directory list of all the neighborhood association leaders and contacts in the Columbia city area. These leaders they were able to send the survey to homeowners in their neighborhoods. These contacts provided opportunities to reach out to the neighborhood association leaders to inform them about my research survey and to encourage participation. To create an easy experience for involvement, I used Qualtrics to design, distribute, and analyze survey data.

The IRB approved the research including survey and the participation recruitment email on February 4, 2021. Then February 9, 2021, the recruitment emails were sent out to 31 neighborhood association leaders. After two weeks another email was sent out on February 25, 2021 to the homeowner's association leaders notifying them that the survey was extended and reminding/encouraging them to participate in the research survey.

Choosing A Research Strategy: In general a "landscape is both about the 'phenomenon itself and our perception of it' (Brink, A. (2016) pg. 21)" this is why "landscape architecture research is designed to expand our knowledge related to the shaping of landscapes and to processes of landscape intervention at various scales" (Brink, A. (2016) pg. 20). The objective of this research is comparing different types of lawn alternatives, the most effective use for completing the survey is using a quantitative research method. Using the qualitative method allows for "testing objective theories by examining the relationship among variables, these variables then can be analyzed using statistical procedures" (Creswell, J. (2009) pg. 22). The final question of the survey is a qualitative question that works to "explore and understand the meaning individuals or groups ascribe to a social or human problem," (Creswell, J. (2009) pg. 22) which in this case is asking an open-ended question allowing the homeowner to freely express their thoughts about lawn alternatives and "the researcher making interpretations of the meaning of the data" (Creswell, J. (2009) pg. 22). While using both "approaches may be used sequentially, concurrently and iteratively, or in a sandwich pattern," (Sandelowski, M. (2000) pg. 246) it is these combinations "at the method level can be used to expand the scope of the study to capture a broader dimension of the problem" (Sandelowski, M. (2000) pg. 247). Thus, giving the research data a dynamic analysis of the situation.

Survey Development: The initial version of the survey was 16 questions asking homeowners a series of multiple-choice questions concerning lawns decisions and if they were willing to transitions to different lawn alternatives. The survey went through 5 revisions through consultation with research mentor Dr. Robert Walsh before changing the survey to a more visual format.

Final Survey Format: The objective of these revisions is to figure out the right questions to ask and the number of questions to ultimately design a survey that would be effective and simple for the participants to respond to. This new format compared sets of new lawn alternatives and would have the participants choose which solution they thought would be the best for them and their home. This would create an easier format for the research participants while reducing the extent of time that is required to complete the survey. The survey required the homeowner to make comparisons between hardscapes, untreated lawns, native plantings, ground cover, gravel, asphalt, gardens, and trees with mulch. (To view the complete survey sent to homeowners see Appendix.)

Findings

The survey was used to gather homeowners' views and perceptions of new lawn alternatives. The data showed that homeowners would be willing to transitions to different lawn alternatives and some even mentioned that they had change over already. The data shows that out of all the alternatives, homeowners would be more likely to make the change to native plantings with a total of 45% of homeowners stating that this was the most preferred option.

In the short answers part of the survey when the homeowners could state that they had liked or disliked about the options provided, 4 out of the 20 responses stated that they have already transitioned to native plantings and then an additional 5 stated that they thought that native plants would be an option that they would readily switch to. One homeowner stated, "we need a paradigm shift in how we manage our yards. Way too much water and energy go into mowing grass and maintaining ecologically malignant, non-native plantings." Another viewpoint that was received is that homeowners would like to use a combination of these alternatives together but there was

also some concern expressed about "not knowing how to care for specific plants". Some homeowners also stated that they were not particular about what they planted but that they just wanted vegetation that was green. Only one of the participants wanted to continue to implement grass even if they could no longer use herbicides and pesticides on their grass. Homeowners were asked which part of their yard they would be more willing to transition: the back or the front. The results from this question show that there is almost an even split between the back and front yard with 43% saying that they would transition their backyard while 56% stating that they would prefer to implement alternatives into their front yard.

Discussion and Conclusions

Based upon the research data gathered, native plantings are a solution that homeowners would, and some have already implemented into their yards. Many of the homeowners who were contacted for the research were very positive about changing their lawns to a sustainable alternative, this could mean that homeowners are becoming more aware about the impact that they and their home play on the environment and that they have a opportunity to help. Making this transition to different alternatives would require a new understanding of how to take care of their yards and this lack of knowledge could be the reason why some homeowners are reluctant to make this change. More knowledge and better more abundant resources for homeowners could help to make this transition easier to encourage homeowners to change instead of relying on the default grass lawns and turf. Homeowners want something additional types that just one. With this survey it was an either-or situation where homeowners explicitly stated that in their yards they would prefer to have a combination of new alternatives like native plantings, trees with mulch and hardscapes to provide a more diverse yard landscape this shows that homeowners are not looking for a simple solutions but would like a yard design that is catered to their needs and goals.

This research project took place in a suburban area in central Missouri. The location that this data was collected could influence the results of the research, for instance if this project were conducted in a rural area or an urban area it could affect homeowners' preferences. Also, this research was only able to target a small sample of the population so a larger reaching research project would be needed to better understand homeowners' preference. Also, the geographical location of the testing could influence the results of the survey for instance, if the survey was hypothetically conducted in arid southwest in the United States there might be more homeowners who would choose to implement hardscapes instead of native planting.

Conclusion: This research shows that homeowners are open to the idea of making the transition to a sustainable alternative especially to native plants, while some homeowners have already made the transition there are some homeowners who are reluctant because of the lack of knowledge they possess about plants. This research shows that landscape designers and other marketing services should focus on making information and alternative products as readily available to homeowners as grass lawn is to them. Providing resources about these sustainable alternatives especially native plantings would make it a readily available alternative to grass lawns, and homeowners are willing to make the transition they just need a helping hand to guide them along the way.

Appendices

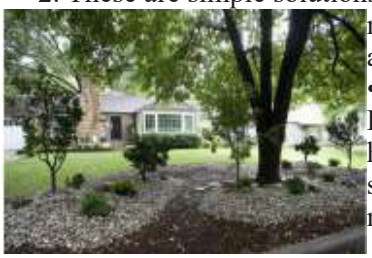
Final survey used in *Qualtrics* distributed to possible research participants:

> Thank you for taking the time to complete this survey for my McNair Scholar research project. The topic of my research project concerns grass lawn alternatives and the preferences of homeowners. The focus of this research is not on the lawn itself, but on better understanding the preferences of neighbors and homeowners concern which alternative strategies could be most promising.
>
> Better understanding how we can preserve or even improve the character and enjoyment of residential neighborhoods, really matters. While it is true that water shortages are currently more of a factor in other places like Phoenix Arizona, nevertheless the grass lawn is now so commonplace that your perspective would still be helpful.
>
> Participation in this survey is completely voluntary. Responses will remain confidential and anonymous and no personal information is required. You may decline altogether and there are no known risks to participate beyond those encountered in daily life.
>
> If you have any question or concerns, please contact me at clscxz@mail.missouri.edu. If you want to talk privately about your rights or any issues related to your participation in this study, you can contact University of Missouri Research Participant Advocacy by calling 888-280-5002 (a free call) or emailing MUResearchRPA@missouri.edu.
>
> The survey consists of 12 questions and should take between 5-10 minutes to complete. Thanks again for your help and insights!
>
> 1. These are two options that promote plant diversity and provide habitats for insectpollinators. Which alternative do you prefer?

• GARDEN: Encourages plant biodiversity, edible food, provides habitat for insect pollinators

• NATIVE PLANTING: Provides plant diversity, suitable for growing without water or maintenances, pays homage to native plants, distinct and individual to different regions

2. These are simple solutions that require less maintenance. Which alternative do you prefer?



• TREES WITH MULCH: Provides shade which can help with cooling cost in summertime, does not require mowing

• UNTREATED GRASS: Does not require watering and pesticides, it not a ecologically friendly as other options and requires to be mowed

3. These are solutions that utilize native plants and trees. Which solution do you prefer?

• NATIVE PLANTING: Provides plant diversity, suitable for growing without water or maintenances, pays homage to native plants, distinct and individual to different regions

• TREES WITH MULCH: Provides shade which can help with cooling cost in summertime, does not require mowing

4. These are solutions that require different interactions with the yard space. Which alternative would be more effective for you?
• HARDSCAPE: Low maintenance after installation, creates a usable space for organized outdoor activities
• GROUND COVERING: Thick covering, doesn't require mowing, wide variety of plants can be used

5. These are solutions that provide monotonous yard coverage. Which solution do you prefer?
• UNTREATED GRASS: Does not require watering and pesticides, it not a ecologically friendly as other options and requires to be mowed
• GROUND COVERING: Thick covering, doesn't require mowing, wide variety of plants can be used

6. These are alternatives that encourage outdoor activities. Which alternative would be best for you?
• HARDSCAPE: Low maintenance after installation, creates a usable space for organized outdoor activities
• GARDEN: Encourages plant biodiversity, edible food, provides habitat for insect pollinators

7. These two solutions provide large space for kids to play on. Which of these do you prefer?
• ASPHALT: Does not require water or regular maintenance. Does not allow rainwater to naturally soak through.
• UNTREATED GRASS: Does not require watering and pesticides, it not a ecologically friendly as other options and requires to be mowed

8. These solutions provide an alternate option for ground cover instead of grass. Which new alternative do you prefer?
• GRAVEL: Allowing water to naturally drain, can combine with plants, lower maintenance
• GROUND COVERING: Thick covering, doesn't require mowing, wide variety of plants can be used

9. These alternatives allow for outdoor events. Which alternative would be more effective for you?
• HARDSCAPE: Low maintenance after installation, creates a usable space for organized outdoor activities
• ASPHALT: Does not require water or regular maintenance. Doesn't allow rainwater to naturally soak through.

10. Which option do you like the most?
GARDEN
UNTREATED GRASS
ASPHALT
TREES WITH MULCH
HARDSCAPE
GROUND COVERING
NATIVE PLANTING
GRAVEL

11. Which yard would you be more willing to change to the new alternatives?
• Back Yard
• Front Yard

12. What is something that you liked or disliked about these new lawn alternative options?

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Problem-solving Abilities and Survival Rates in *Anolis sagrei*

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Her undergraduate research proposes questions about ecologically relevant cognitive behaviors in the Chipojo lab with Dr. Manuel Lead.

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Abstract
The majority of cognitive studies on animals have been done in laboratory settings. Studying cognition in the laboratory does not diminish the result of the study, though there is an increased chance that the subject is not responding the same way that it would if it were in nature (Pritchard et al. 2016). A majority of studies assessing problem-solving are concentrated in a small number of bird and mammal species. The problem-solving abilities of lizards have been relatively less explored, though it has been suggested that they are capable. To test the problem-solving abilities of free-living *Anolis sagrei* we presented them with the cylinder task in the field. The cylinder task requires that the lizard resist the natural instinct to lunge at prey and enter the cylindrical apparatus through one of the open sides. This study evaluates if the problem-solving abilities in a population of *A. sagrei* predict fitness by assessing their survival rates in the field. Due to insufficient sample size, we were not able to support the hypothesis that problem-solving ability correlates to survival.

Introduction
The role of cognition within natural conditions has been increasingly studied in non-human animals, what is referred to as cognitive ecology. Behavioral flexibility, problem-solving, and other cognitive abilities are predicted to be favored in animals due to their ability to adjust behavior in diverse and complex environments. This can be viewed in the context of diet, habitats, and social structures (Leal and Powell, 2011). Research done in cognitive ecology is concentrated on a small number of bird and mammal species. Certain species, such as corvids and primates, are known for their exceptional tool use and novel problem-solving. In Sendai city, Japanese crows learned to drop nuts onto pedestrian crosswalks, then wait until traffic lights turn red to land on the street and gather food from the broken nut (Clayton and Emery, 2008). Chimpanzees have also been known to use a wide variety of tools that they create by stripping leaves off sticks (Mcgrew and Tutin 1973).

The historical bias for mammals and birds has left a gap in the knowledge of problem-solving in reptiles. Reptiles are found nearly all over the globe in both land and sea. A majority of this diversity (96.3%) comes from Squamata, and within that subsection, lizards are the most diverse (59%) (Pincheira-Donoso et. al, 2013). The lizard genus

Anolis contains 361 species as of 2005. *Anolis* are generalist foragers and inhabit diverse conditions. They are found in many habitats across the neotropics and have invaded the Hawaiaan islands, Taiwan, and Japan (reviewed in Losos, 2011).

Though there is comparatively less data for lizards, there is evidence of problem-solving comparable to that found in birds and mammals. For example, they use different strategies to solve the novel task of moving a disc covering a food reward. In the scenario there were two different colored discs, and they demonstrated associative learning by correctly choosing the blue disc that covered the reward instead of another disc that had nothing beneath it (Leal and Powell, 2011). A single previous study showed that by using a modified version of the cylinder task, *Anolis sagrei* are able to resist the instinct to lunge at their prey to complete the task within natural conditions (Storks and Leal, 2020).

The majority of cognitive studies have been done in laboratory settings. Studying cognition in the laboratory does not diminish the result of the study, though there is an increased chance that the subject is not responding the same way that it would if it were in nature (Pritchard et al. 2016). For example, non-tool-using species have developed tool use in captive conditions (Goodman et al. 2018). Though this demonstrates cognitive behavior, it has little ecological significance since the animal does not typically interact with its environment in that way. Laboratory testing also limits the number of species that can be tested since they must behave under novel laboratory conditions. Some researchers have suggested that cognition should be tested in the field whenever the question is addressing an ecological tendency or when a test can be adapted for field use (Pritchard et al., 2016).

Fitness is defined as the ability to leave viable offspring, and can be measured by determining how likely an organism is to survive and/or reproduce. A correlation between cognition and fitness has been widely assumed in the past, and some studies have recorded such a correlation (reviewed in Pritchard et al. 2016). A study on the great tit provided direct evidence of cognition relating to fitness by capturing the great tits to obtain cognitive data then returning them to the wild to collect reproductive rates (2012). Females that solved the problem in captivity had increased reproductive rates compared to females that did not solve the problem (Cole et al. 2012). It is difficult to collect survival rate data in the laboratory since animals do not face the same ecological pressures, such as predators or obtaining their own food.

In our experiment, we presented the animals with a detour task, which is a commonly used method of analyzing an animal's ability to access a reward that it can see but not directly get to. By using a cylindrical apparatus with a removable transparent top, we tested the ability of individuals to retrieve a reward by detouring around a barrier. In nature, there are few transparent objects, making the likelihood that an animal would encounter one low. This presents the animal with a novel problem. The detour task is used to study a variety of traits, but in this study we focus on inhibitory control, by requiring the lizard to diverge from their typical sit-and-wait foraging method where they quickly lunge at moving prey, and learning, by presenting the task multiple times (review in Losos, 2011)(Kabadayi et al., 2017).

I hypothesize that over time and trials, lizards will learn how to successfully complete the detour task. A previous study found that *A. sagrei* could solve this task under natural conditions. Because transparent objects are rare within their natural habitat, this task likely presents a novel problem that requires lizards to modify their typical sit-and-wait foraging method (reviewed in Loso 2011). I also hypothesize that lizards who solve the detour tasks will be more likely to survive. Successful solving of the task might indicate a lizard's ability to innovate, which means they may be more likely to exploit new resources and thrive in a wider variety of environments, leading to greater probability of survival (Sol et al., 2005).

Literature Review

There has recently been a push in the field of cognitive ecology to conduct experiments under natural conditions. By testing animals in their natural habitat, researchers are able to test animals that may not be able to be tested in the lab, relate fitness to cognition more easily, and observe more natural responses to experiments.

Cognitive research has been concentrated on a relatively small number of bird and mammal species that are likely to behave under laboratory conditions. In this context, behaving could refer to the animal's willingness to readily eat, perform behaviors in question, or mate in the laboratory. They also need to be safely transported from their habitat to the laboratory, which is heavily reliant on their size (Pritchard et al., 2016). For example, the mouse is a model organism for cognitive research because of its ability to live in the laboratory with conspecifics, to easily and safely be transported in cages, and to cooperate in novel environments with observers. Scientists have recently recognized that looking at a small number of species limits the available data on animal cognition, which can result in an incomplete understanding of the field.

One widely accepted way to broaden the number of species included in cognitive ecology data sets is to study organisms in the wild, where they are more likely to cooperate. For example, in Benson-Amram and Holekamp's study on innovative problem solving in wild spotted hyenas they provide evidence that hyenas are capable of opening a latch bolt to obtain a food reward. This study suggests that hyenas with diverse initial exploratory behaviors are most likely to successfully open the latched box (Benson-Amram and

Holekamp, 2012). By studying the hyenas in the field and making observations from a distance as to not interfere or distract the subjects, this study has provided cognitive data on a territorial animal that is not often studied in the laboratory possibly due to their size, aggressiveness, and pack animal lifestyle.

Very few studies have related cognitive ability to fitness. One reason is that in cognitive studies, animals are typically selected for their cognitive ability or a peculiar tendency and not their rate of reproduction or survival abilities (Pritchard et al., 2016). Out of the ones that have, it is more common to study reproductive success than survival rates. This may be because some animals are willing to mate in the laboratory. Since animals in the laboratory do not face the same ecological pressures, such as predators or obtaining their own food, it is extremely difficult to collect relevant survival data. The field allows for natural social interactions to influence these rates, for example social learning in the American crow influences antipredator responses (Lee et al. 2019). Animals in the lab can also experience increased levels of stress after being removed from their environment that results in decreased survival or reproductive rates (Balcombe et al. 2004).

In Cole et al.'s study on the great tit, direct evidence of cognition relating to fitness is provided by capturing the great tits to obtain cognitive data then returning them to the wild to collect reproductive rates (2012). Females that solved the problem in captivity had an increase in reproductive rates compared to females that did not solve the problem. Many variables were noted in this study, but the only significantly different variable between the solvers and nonsolvers was that solvers were more efficient foragers (Cole et al. 2012).

The last major benefit of performing experiments in the field is that animals are more likely to naturally respond to experiments when they receive typical cues from their natural environment. By testing in the field the animal performs the behavior in a much more natural way than in the lab since they are less stressed, are internally motivated, and have all of the surrounding stimuli that they encounter daily. Though animals in the field are not stress free, naturally occurring stress and laboratory induced stress may alter behavior in different ways (Pritchard et al. 2016).

Laboratory situations may be more stressful for animals. Laboratory stress is different from stress in the wild because animals can not choose to disengage with a stressful activity as easily. In the wild they can choose to leave the area, but in the laboratory they are confined by a cage or fence. Stress may affect an animal's performance by altering its motivation and behavior, and if an animal is tested while it is stressed it may appear that the animal is unable to perform a task when in reality it is too stressed to do so (Pritchard et al. 2016). Minimizing additional stress is necessary to see how an animal responds to novel stimuli in low-stress environments. This can be successfully done by testing animals in the wild.

Lastly, animals are more likely to respond naturally to novel stimuli when they are surrounded by their typical environment and stimuli compared to the laboratory where there is a lack of stimuli. Since the animals are accustomed to the abundance of stimuli in the wild the lack of information in the laboratory can limit global information that animals use to make decisions (Pritchard et al. 2016). Testing organisms without this information means that the results are not a natural reaction, which has little ecological value and is not representative of the animal's full capabilities. Though, by doing an experiment like this in the field there are many variables and incoming stimuli which makes it difficult for the researcher to determine what the animal is taking into consideration and what the animal is ignoring (reviewed in Pritchard 2016). This is a common tradeoff in studies done in the laboratory versus the field.

Performing experiments in the field has its own challenges. One being that it can be difficult to motivate animals to complete the task in the field, since there is other food that does not require them to complete a task to get. Animals may learn quicker or complete more tasks in the laboratory. Captive kea learned how to lift a tube quicker than wild kea did, and captive spotted hyenas were more successful at approaching and solving novel tasks than wild spotted hyenas (review in Pritchard et al. 2016). Lastly, field experiments can be difficult to recreate because of the specific environment that is created by the animals. For example, in a study questioning if wild jackdaws are able to identify a threatening person they selected an environment where non threatening humans regularly walked around, persecution of corvids occured, and there was frequent monitoring during breeding situations (Lee et al. 2019).

These specifics would make it difficult to recreate this field site. Despite these challenges, field studies are useful because they allow researchers to obtain new information on animals that are not easily tested in the laboratory, and gain insight into the natural cognitive capabilities of animals. Overall, performing cognitive field studies has a lot of unique benefits that allow different animals to be studied, allow researchers to incorporate the animals life history, and reveal natural behaviors that may not be seen in the laboratory. As other fields, such as technology and genetics, progress it allows more to be accomplished with cognitive

field studies. Biologgers and computer vision have changed these studies, and researchers are now able to follow animals for long periods of time, over long distances, and with intense detail.

Methods

In June 2018, 191 adult *A. sagrei* (109 females, 82 males) were released on two experimental spoil islands in the Indian River Lagoon Aquatic Reserve in Fort Pierce, Florida. These lizards came from a single source island. We marked each individual using a permanent, unique bead tag sewn into the tail for identification and collected their weight, snout to vent length (SVL), and sex. Lizards were acclimated for a minimum of 14 days.

Testing Apparatus

The testing apparatus was a transparent half cylinder (Figure 1). One end of the cylinder was striped pattern and the other end in a checkered pattern to assess preference for visual cues. The apparatus was randomly placed through the trials, so the striped and checkered sides were not consistently on the same side. Both ends are open to the center of the apparatus, providing access to the reward, a maggot that is secured at the center with a hook of surgical wire.

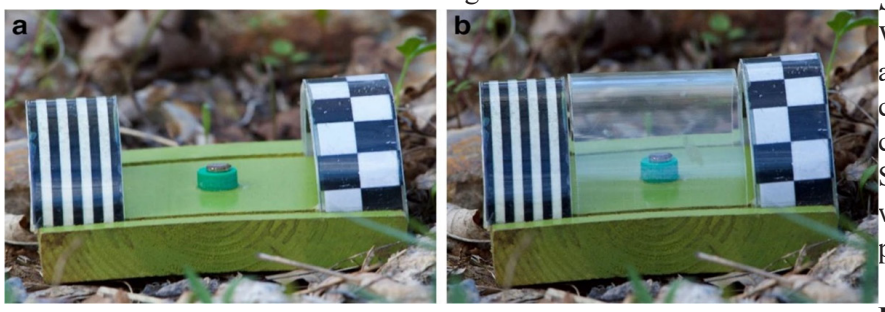

Figure 1: The detour apparatus used in this study (adapted from Storks and Leal 2020). a Apparatus without transparent covering. b Apparatus with transparent covering.

Trials

We initiated a trial when a lizard was spotted by placing the apparatus on the ground within 1 m of the lizard. A trial started when the apparatus was placed, and ended after 10 minutes. All trials were recorded using a GoPro, which provided footage of a three to five foot radius around the apparatus. The trial continued until the lizard successfully captured the reward or the 10 minutes had elapsed. If a non-focal lizard interrupted the focal lizard's trial by coming within one SVL of the apparatus, we immediately ended the trial and did not include it in the data analysis.

Consecutive trials for the same lizard were separated by a minimum of 30 minutes and each lizard could be tested several times a day. Trials in which the lizard did not approach the apparatus were aborted and not included in the analysis. We defined approaching the apparatus as the anole getting one body length away from the apparatus.

Lizards were first habituated to the apparatus. To do this, we presented the lizards with the apparatus without the transparent cover blocking the lizard's access to the reward. During habituation, lizards did not have to enter through the checkered or striped sides, and oftentimes they walked through the part of the apparatus that is covered in later trials. For each habituation trial we measured how long it took the lizard to approach, and whether the lizard failed or succeeded to get the reward.

During detour trials, the apparatus was presented with the transparent plastic covering over the center. The lizard was only able to get the maggot by entering the open ends of the apparatus. In the detour trials,we measured the time to approach the apparatus, whether the lizard successfully got the reward, the end through which the lizard accessed the reward, and the number of errors. An error is counted when a lizard's snout continuously contacts the transparent covering, as if it were lunging for its prey. Lizards solved the detour problem when they successfully accessed the reward in 5 of their 6 previous trials.

Survival

We returned to the islands in March 2019 to assess survival of lizards tested above. We captured the surviving lizards by exhaustively clearing the islands of lizards. We recorded their SVL and weight upon capture. These parameters will be compared with the individual's overall performance.

Data Analysis

Videos of each trial were analyzed using Behavioral Observation Research Interactive Software (BORIS). As part of the analysis we extracted the time it took the lizard to approach and complete the trial, the number of errors the lizard made during the trial, and the number of times the lizard retreated, or moved a distance greater than two SVL from the apparatus. The orientation of the apparatus, and the occurrence of interference in a trial was noted in the field. Video analysis confirmed the outcome of the trial which was reported in the field notes.

These variables were statistically analyzed using R statistical software. We used a linear mixed effects model to test for improvement across trials by regressing the number of errors on scaled trial number with individual as a random effect. We restricted this analysis to only individuals that solved the task and only included successful trials in the analysis. We tested for the effect of performance on survival. We compared the proportion of lizards that solved the task to survival using a Fischer's Exact Test.

Results

Of 191 lizards, 39 of them completed habituation. Of those, 8 lizards did not interact with the detour apparatus when presented. Out of the 31 lizards that did interact with the detour apparatus, 24 solved the task by passing the criterion of completing 5 out of 6 consecutive trials (Table 1). The 7 lizards that failed the task completed at least 5 detour trials but did not reach the criterion (Table 1).

	passed	failed	total	Average number to meet criterion
habituation	39	152	191	6.17 trials
detour	24	7	31	7.42 trials

Table 1: The number of lizards that participated in the two different types of trials, and the average number of trials it took for lizards to meet criterion

After standardizing the number of trials each individual lizard completed, there was no significant increase or decrease in the number of errors as lizards solved the task (Figure 2). Out of the 24 lizards that passed the criterion for the detour task, 5 survived. Out of the 7 that did not meet this criterion, 1 survived. Survival did not show any correlation with problem solving success, but this sample is likely not large enough to determine if problem-solving ability and survival rates are correlated (Table 2).

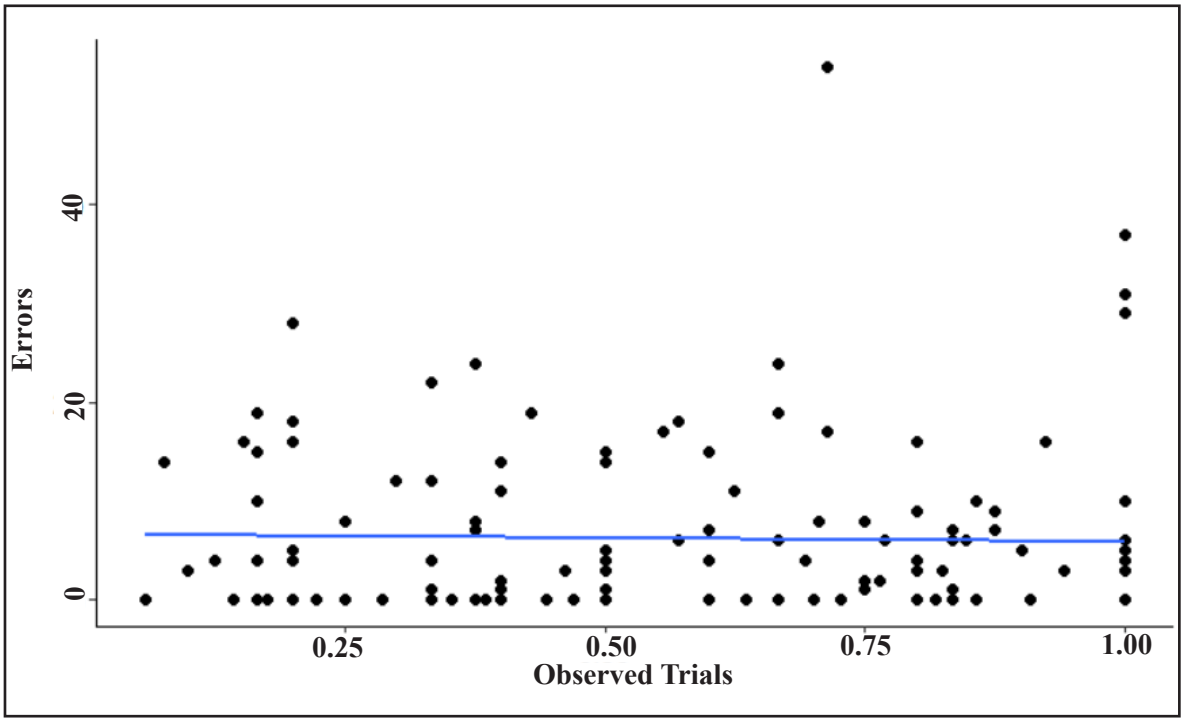

Figure 2: The relationship between scaled trial number and the number of errors lizards made while solving the detour task. Observed trial numbers were scaled for each individual between 0 and 1 by dividing each trial number by the number of the last trial for each individual. The errors are the number of errors one individual made during one detour task.

	survived	deceased
pass	5	19
fail	1	6

Table 2: The number of lizards that did and did not survive the year time period, and how many passed or failed the criterion (successfully completing 5 out of 6 consecutive trials) for the detour task. The p-value is 1 because not enough lizards survived the year to detect any significant correlation between problem-solving ability and survival

Discussion

A large proportion of lizards successfully completed the detour task, demonstrating thatlizards are capable of solving this problem in the field. By reaching criterion, it is likely that the lizards learned over time. During this time, the lizards did not improve their performance demonstrated by the relationship between observed trials and errors (Figure 2). This is unlike a previous study by Storks and Leal (2020) which showed that lizards improved performance across trials on average in the same detour task. The study by Storks and Leal (2020) evaluated a native population of lizards in the Bahamas, whereas in this study we evaluated an invasive population in Florida. A possibility as to why the native population had a decrease in error numbers across trials during the detour task and the population in this study did not is that *A. sagrei* is an invasive species in Florida. Therefore, invasive species may have a trade off between persistence and learning. Being persistent is to continue attempting a task without giving up, and could be beneficial to invasive species. In order for a non-native species to be successful, they must either outcompete native species using a pre-adapted trait or trade-off, or fill an unoccupied niche with a different trait or trade-off (Mathakutha et. al, 2017). In ant colonies, variability in personality traits contributes to the ecological success of native and invasive ant species. The invasive species exhibited higher exploratory activity, which might be related to persistence and could contribute to the success of the lizards on the detour task despite lack of improvement. Future studies will evaluate how exploratory

behavior contributes to success in solving the detour task (Blight et al., 2016).The invasive species exhibited higher exploratory activity, which might be related to persistence and could contribute to the success of the lizards on the detour task despite lack of improvement. Future studies will evaluate how exploratory behavior contributes to success in solving the detour task.

Another goal of our study was to determine if lizards who successfully completed the detour task were more likely to survive, potentially connecting cognitive ability and fitness.. After returning a year later, not enough of the population survived to detect a significant difference between those that did and did not pass the detour criterion. Our lack of power to test this goal may be because a year was too long to wait to return. The Florida winter potentially negatively affected the entire *A. sagrei* population over this time span regardless of cognitive ability. In this case, the relatively high mortality rates suggest that cognition does not aid in winter survival. Likely, non-cognitive traits such as thermal physiology contribute more to winter survival." If we were in the native range, perhaps cognitive ability would play a larger role in survival, as winter mortality is not a factor.

There is a strong history suggesting individuals with better cognitive abilities are more likely to survive, but few studies have actually tested this. This study has provided an effective method for collecting data on correlations between fitness and cognition. We did not find a correlation between fitness and cognition over a year timespan. In order to increase the potential power of future studies, we suggest increasing the number of visits to the site so that the population is being recorded three or more times throughout the year. More visits might provide higher resolution of survival probability at a scale where cognitive ability may be important.

By testing free-living anoles we are able to record data on task-completion, traits that affect performance, and ecologically relevant survival data that may not have been achievable in the laboratory. These methods and data emphasize that cognitive studies can be conducted in the field, and that species that are not normally considered for cognitive studies can perform novel tasks in the field. As the first study to assess the problem-solving abilities of an invasive species of lizards, it has contributed valuable quantitative data to the field. We now know that cognitive ability has no effect on survival of tropical lizard species over a year timespan. This study has also provided evidence that the detour task, which has commonly been used to test traits of mammals and birds (Kabadayi et al., 2017), can successfully test the same traits in lizards under natural conditions.

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Cardiac Stiffness and Left Atrial Stretch of the Young and Aged Myocardium

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Introduction

Abstract – Atrial fibrillation (AF) is the most common cardiac arrhythmia and is most prevalent in aged individuals. Stretch of the myocardium is a risk factor for AF, and the aged myocardium exhibits chronic stretch. The goal of this project is to investigate the extent of left atrial stretch in a mouse model of aging. To accomplish this goal, we used isolated hearts of young (3-5 month) and aged (19-28 month) C57BL/6 mice subjected to atrial preloads of 0 cm and 12 cmH20 (i.e., increasing stretch), and monitored left-atrial dimension using video microscopy. Our data reveal that atria of both young and aged mice exhibit greater dimension at 12 cmH20 compared to 0 cmH20 ($P<0.05$, main effect of pressure). Furthermore, the left-atrial dimensions of hearts of aged mice were greater ($P<0.05$) than those of young mice at both 0 cmH20 and 12 cmH20 ($P<0.05$, main effect of age). Our data revealed, age-associated atrial remodeling, and atrial stretch in both young and aged atria. Future studies will examine the incidence of stretch-induced atrial arrhythmias in young and aged hearts and provide pre-clinical data on mechanisms of age-associated AF. The long-term goal of this project is to guide, diagnosis and treatment of AF in elderly populations.

Atrial Fibrillation (AF) is a cardiac irregularity affecting more than 2.7 million Americans (1). Over the next decade, 12.1 million Americans will have AF (affecting over 9.4 additional Americans) (2). Atrial fibrillation is a type of atrial arrhythmia where abnormal electrical signaling causes the heart to “quiver” and not sufficiently pump blood from the atria into the ventricles. The primary cause of death in the setting of AF is fatal stroke, due stasis of the blood in the atria and a higher incidence of blood clots (3). Elderly populations are at particularly high risk for AF, with a prevalence of more than 10% in individuals over the age of 80 (4).

Literature Review

Fibrosis as a contributing factor to AF – Most data indicate that AF is linked to cardiac structural remodeling in the atrial myocardium, including extensive extracellular matrix deposition within the atrial walls of AF patients. Consistent with these data, in atria of aged mice fibrosis is observed along with increased expression of matrix components Collagen I, Collagen III, and fibronectin, as well as with altered levels of matrix metalloproteinases and tissue-inhibitor of metalloproteinases (5, 6). Fibrosis leads to

changes in electrical condition speed across atrial tissue, and when combined with age-associated changes in atrial structure and geometry promotes initiation and maintenance of AF (7-9). Permanent fibrotic remodeling occurs in patients with AF in comparison to individuals living without AF. There is also an epidemiological link between AF and age-associated risk factors such as hypertension, ischemic heart disease, & diabetes and AF (10-12). Taken together, these published studies show a striking link between age and incidence of AF.

Atrial Fibrillation Factors – It is well established that atrial stretch leads to an increase in triggered activity and AF suggesting mechano-electrical feedback may underlie AF pathogenesis in the chronically stretched atrium (13-15). In mitral valve disease, patients' left atrial size correlates to the likelihood to the development of atrial fibrillation. The initiation of atrial fibrillation or atrial flutter can be linked to numerous different contributing factors such as; obesity (16), amount of physical activity (17-19), advancing age (20), and hypertension (21). Many of these factors have been found to have epidemiological impact on cardiac electromechanical issues that positively correlate with the occurrence of AF in patients. Although there is debate on what exactly starts or arrhythmic beats, AF has been linked to an increase in pressure, atrial stretch, the opening of ion channels, and increased chamber volume (22). However, it is unclear if the aged heart is excessively sensitive to acute stretch because age-associated fibrotic remodeling processes may limit atrial stretch.

Current Treatment strategies for Atrial Arrhythmias – Current clinical AF treatments include various medical procedures, medication, supportive care, and surgeries. There are 2 types of medical procedures used to treat AF which are cardioversion or catheter ablation. Cardioversion involves the usage of electrical shocks to reestablish normal heart rhythm in those with erratic cardiac arrhythmias. The other form of medical treatment is catheter ablation, abnormal tissue in the atria is then removed using electrical energy. Both cardioversion and catheter ablation are effective at reducing AF occurrence, with success rates of between 70-90% (23-25). Several pharmacological approaches are also effective at treating AF. Beta-blockers reduce adrenergic influence on atrial pacemakers, slow heart rate and conduction, and decrease blood pressure, which are all beneficial in the setting of AF (26-27). Calcium channel blockers can also be used to slow heart rate, decrease electrical conduction speed, and relax blood vessels to reduce blood pressure (28-31). With respect to stroke prophylaxis, anticoagulants such as warfarin are effective at reducing blood clotting and AF-associated stroke (32). Common surgeries to remediate the issue of atrial fibrillation are mostly coronary bypass procedure, that allow the redirects blood around a section of a blocked or partially blocked artery in your heart to improve blood flow to your heart muscle.

The goal of this project is to provide new basic science insight into the extent of stretch in the aged atrium, which may lead to future studies targeting stretch-activated ion channels in the setting of aging-associated AF.

Methods

Animal procedures were approved by the Animal Care and Use Committee at the University of Missouri (Approval reference number 9581) and complied with all US regulations involving animal experiments. Male and female C57BL/6 mice were studied at ages of 3-5 (Young) or 19-28 months (Aged). Mice were anaesthetized with an intraperitoneal injection of ketamine: xylazine (100 mg/kg:5mg/kg) and hearts were rapidly (~30 s) excised for subsequent experimentation. Hearts were cannulated via the aorta and perfused with Krebs-Henseleit buffer (KHB) containing (in mmol/L): 118 NaCl, 4.7 KCl, 1.8 CaCl2, 1.2 MgSO4, 1.2 KH2PO4, 25 NaHCO3, 11.1 Glucose, 0.4 Caprylic Acid, 1 Pyruvate, and 0.5 Na EDTA. The pulmonary vein was then cannulated and perfused with KHB to obtain left-atrial pressures of 0 and 12 H2O. An octopolar electrical catheter was inserted into the left atrium to record left-atrial electrical activity and provide programmed electrical stimulation protocols. The programmed electrical stimulation protocols are outside of the scope of the present investigation. Atrial stretch in response to pressure elevation was monitored using a Leica Flexacam camera system, with diastolic atrial dimensions analyzed with NIH ImageJ software. The area of the relaxed atria was quantified by outlining the external area of the left atria with the ImageJ polygon tool. The area in square pixels was converted to mm2 to quantification the 2D surface area.

Statistical analysis – Measurements were obtained at 0 and 12 cmH20 pressure in both young and aged mice, and statistical comparisons were made using factors of pressure and age using a two-way repeated measure analysis of variance (ANOVA). Findings were determined to be statistically significant with $P<0.05$.

Results

Hearts of young and aged mice were cannulated via the aorta and pulmonary vein, and an octopolar catheter was inserted into the atria for electrical measurements for future investigation of atrial arrhythmia (Figure 1, arrhythmia measurements outside of the scope of the present investigation). Following equilibration at 0 cmH20 atrial preload, preload was increased to 12 cmH20 to examine the change in atrial dimension (Figure 2). The left atrium of hearts of aged mice were larger than those of young mice under both preload pressures (Figure 3, Figure 4). Following preload elevation, the left-atrium of hearts of both young and aged increased dimension (Figure 4, Figure 5).

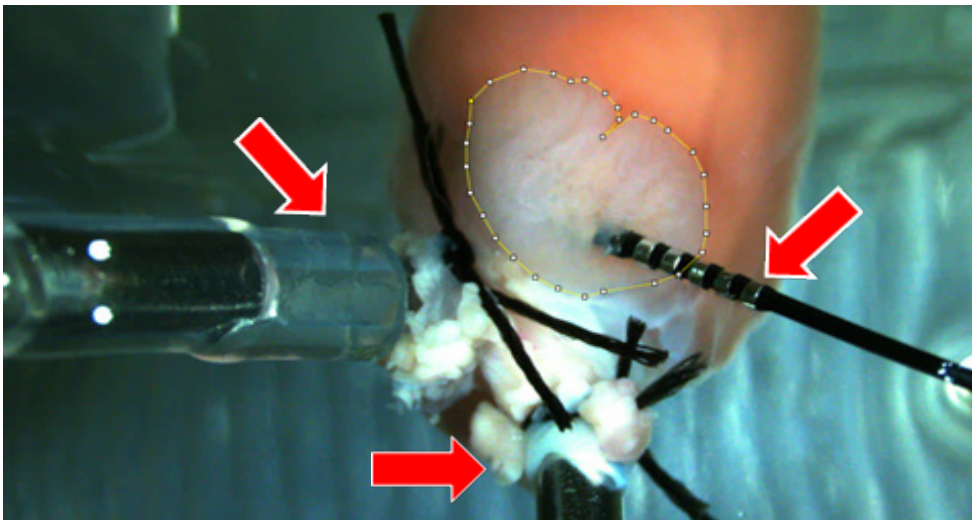

Figure 1: *Mouse working heart preparation*. Example working heart preparation from a young mouse indicating cannula placement. Each tool has been labelled aortic cannula (top left arrow) for coronary perfusion, pulmonary vein cannula (bottom arrow) for preload elevation, and octopolar catheter (top right arrow) for electrophysiological measurements.

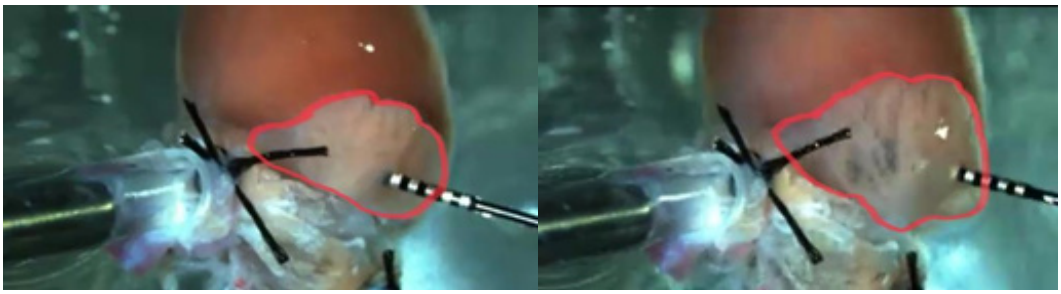

Figure 2: *Example quantification of left atrial dimension*. Example working heart preparation from a young mouse at 0 cmH20 (left) and 12 cmH20 (right) pressure. Left-atrial area used for quantification marked by red polygon.

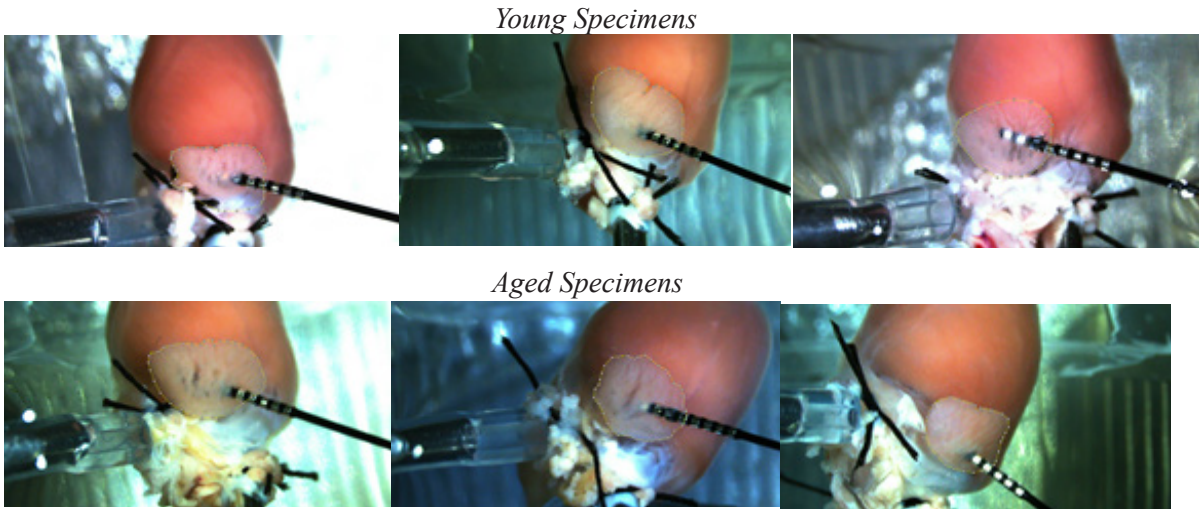

Figure 3: *Example young and aged hearts at 12 cm H20 atrial pressure*. Images of three young (upper panels) and three aged (lower panels) hearts at 12 cmH20.

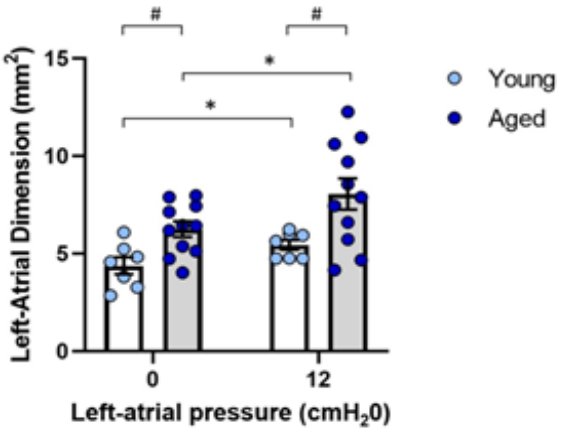

Figure 4: *Left-atrial dimension in young and aged hearts with atrial pressure.* Left-atrial dimension of hearts of young (light blue, n=7) and aged (dark blue, n=11) mice at 0 cmH20 (left panels) and 12 cmH20 (right panels). *<0.05 Young versus Aged, main effect of age. #P<0.05 0 cmH20 versus 12 cmH20, main effect of pressure. Repeated Measures ANOVA.

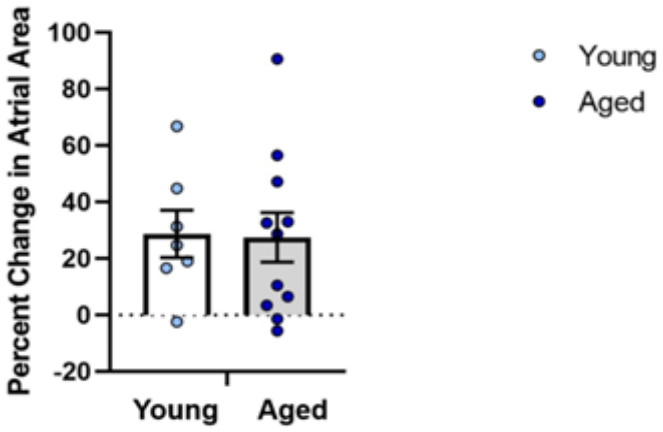

Figure 5: *Percent change in left-atrial dimension in young and aged hearts with increased atrial pressure*. Percent change (12 cmH20/0 cmH20 *100) in left-atrial dimension of hearts of young (light blue, n=7) and aged (dark blue, n=11). Not significant, student t-test.

Discussion

With advancing age the heart remodels (changes size and shape) due to chronic disease most notably hypertension. Most of the remodeling occurs in the left ventricle because of the chronic pressure stress associated with high blood pressure. This can eventually lead to ventricular hypertrophy, which is thickening and enlargement of the ventricular wall. As the ventricle hypertrophies it becomes stiff it does not fill appropriately, there is less passive diastolic filling, and more active filling is required (i.e., atria actively pump blood into the ventricle). This is a trigger for atrial remodeling and fibrosis, with an associated increased risk for conditions such as AF.

Consistent with this literature, we found that hearts of aged mice had an increased left atrial dimension versus hearts of young mice (Figure 4). Qualitatively, hearts of aged mice had visible signs of fibrosis (e.g., Figure 3, white tissue areas in Aged sample 3) consistent with previous investigations in mice (7-9) at this age. Despite this apparent fibrotic remodeling, on average both young and aged atria exhibited the same percent stretch following preload elevation (Figure 5). The left-atrial dimension in aged at 12 cmH20 was more variable than that in young, which is consistent with the biological process of aging leading to phenotypic dispersion (Figure 4). Dispersion in sarcomere length changes (34) and contractile responses (33) in response to ventricular pressure have been reported in mice of this age. Should aging-associated remodeling not limit the extent of stretch, this would create a potential "two-hit" model of disease where atrial remodeling provides a substrate for arrhythmia and residual atrial stretch provides the trigger for arrhythmia on that substrate. The fibrotic transformation of atrial myocardium would result in deterioration of atrial conduction, increasing anisotropy of impulse propagation & building of boundaries that promote re-entry in the atrial wall that maybe directly relevant for the mechanism response for maintain AF.

Future directions – During this experiment, we did not look at the effect that atrial fibrosis has on the heart. In my literature review, I found that the fibrosis contributes to the stiffness occurring from remodeling of the ventricle and atria. This plays a major role in the effect of stretching induce AF. In our specimen we observed white fibrotic tissue in the older mice hearts, which could have played a role in the amount of stretching we analyzed. Fibrosis can be measured in atrial samples frozen from the hearts used in this study.

The next phase of the study will examine the incidence of premature atrial beats and AF following burst pacing protocols. The data were collected in conjunction with the experiments in this investigation. This will allow to assess the interaction between atrial stretch and incidence of AF. Future studies are also planned to use inhibitors of stretch-activated ion channels to reduce AF incidence in the aged heart.

Conclusions:

The left atria of aged mouse hearts have a larger diastolic dimension than left atria of young hearts. In response to an increase in left-atrial pressure, the atria of both young and aged hearts increased their diastolic dimension.

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Terminal Area Energy Management of the Space Shuttle

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Abstract

The Space Shuttle Entry Terminal Area Energy Management covers the guidance algorithm and flight path for a space shuttle's descent back to Earth from an altitude of 85,000-10,000 ft. An alternative two-circle flight path has been developed, along with an algorithm, to execute this flight path using an onboard computer. Various profiles have been developed to understand the properties of the flight as the space shuttle enters the guidance window from different ansgles, quadrants, and distances relative to the runway. Using established simulations we gather velocity, acceleration, elevation, and other properties about the space shuttle during its glide to ensure that it meets all requirements outlined by the National Aeronautics and Space Administration in their published Technical Memorandum 104744.

I. Introduction

The space shuttle is a vehicle designed and built by Rockwell International under contract from the National Aeronautics and Space Administration. From 1974 to 1987 six shuttles were manufactured and delivered to NASA, named respectively: Atlantis, Enterprise, Columbia, Challenger, Discovery, and Endeavour. These vehicles flew a collective 135 missions from 1981 to 2011 conducting manned missions to launch, recover, and repair satellites. This was also critical in the construction of the International Space Station.

The space shuttle was humanity's first ever reusable spacecraft, a key feature NASA was looking for from bidders wanting to build it. Designing it to be reusable meant that the space shuttle would have eminence maneuverability and the sophistication to exit earth's orbit attached to booster rockets, accomplish the mission goals, and return safely back to a designated location. It was designed like a typical aircraft: in order to do so, Rockwell International outfitted the space shuttle with a set of landing gear and a speed brake. One distinct deviation from a typical plane would be the lack of podded engines mounted under the wings. As a result the space shuttle would be unable to generate its own thrust and lift during descent, therefore it would behave as a glider. It would rely on dynamic interactions between the air and its wings to control the fall back to Earth. The vehicle would have

a specific gliding ratio (L/D) of the flight, a property that detonates the unit of horizontal distance the space shuttle can fly for one unit of vertical dissension.

The space shuttle will have a limited horizontal flying range dictated by its gliding properties. Therefore, a pre-planned flight path must be developed in order to ensure that it is capable of reaching a designated landing point before hitting the ground. Managing the conversion rate of potential to kinetic energy perfectly was an absolute necessity. NASA divided that landing process into segments based on the elevation of the vehicle. The Terminal Area Energy Management section of the landing process runs from an altitude of 85,000-10,000 ft. NASA sent out the task to design such a flight path to various labs across the country with specific requirements alongside a list of conditions that the space shuttle would start with. The space shuttle would cross below the 85,000 foot altitude with an attack angle of -10 degrees. It would have a specific heading angle and a velocity of Mach 2.5. They dictated that an acceptable flight path would take the space shuttle from an elevation of 85,000 ft at an initial condition point and deliver it to 10,000 ft at an approach and landing point. During that flight path the space shuttle would be turned from an initial heading angle to a specific heading angle inline with the runway. The vehicle would be required to have a specific velocity at the approach and landing point so that as it exits the boundary the pilot can take control and begin landing procedures.

II. Literature Review

NASA received TAEM guidance flight paths from several groups including JSC, Charles Stark Draper Labs, and Rockwell International, and published their submission in Technical Memorandum 104744. Initial ground track paths, or two dimensional representation of the flight path, Variable Entry Point [Figure 1.1], Racetrack [Figure 1.2], VORTAC [Figure 1.3], Spiral [Figure 1.4] were a part of that release. NASA took these models and developed their own path known as the Hybrid [Figure 2] Model. Simplicity was a major point of emphasis in the development of this track. For the Hybrid Model, computing ground track distance to satisfy the energy dissipation requirements was done using fixed landmarks. This allows for the modification of high energy situations.

Studying these models, NASA distinguished three phases of flight. The Acquisition Phase would be used as a directing cylinder. Its purpose is to take the space shuttle from its initial condition and heading angle towards the designated ground track. The Heading Alignment Cone Phase would contain the actual twists and turns of the vehicle. It is during the primary phase that any relevant energy dissipation technique can be conducted and the vehicle descends most of the elevation range. The Pre-Final Approach Phase is the final segment of the path where the space shuttle is aligned with the runway and flies towards the approach and landing point.

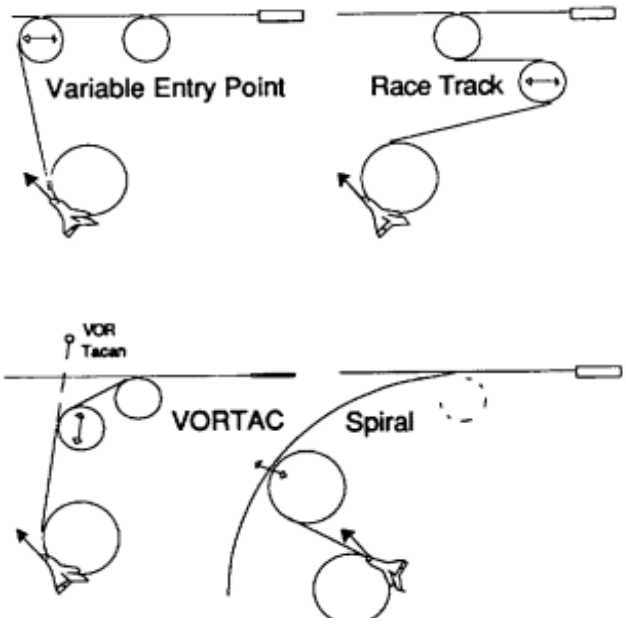

Figure 1. The ground tracks that NASA published in November, 1991.

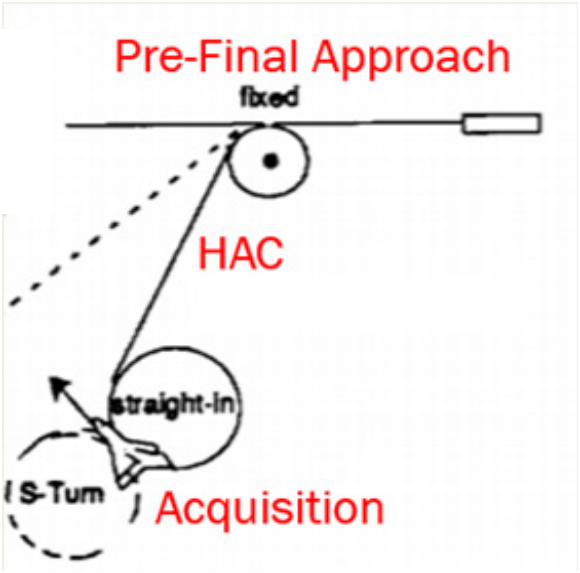

Figure 2. The Hybrid Ground Track Model with the 3 phases of TAEM labeled.

NASA released safety criteria and guidelines that dictate what type of landing procedure would be conducted. Potential procedures include an aborted landing where the crew would parachute from the space shuttle, allowing it to crash if some safety criteria are missed. Enhancing the capabilities of the vehicle by increasing the number of undesirable conditions it can land under will increase the safety factor of the flight. One modification that can be made to the flight path in order to accomplish this is an overhead HAC; it enabled the pilot to avoid thunderstorms that formed at the Kennedy Space Center in Cape Canaveral, Florida. NASA has published ideal ranges of atmospheric conditions under which a landing could be attempted. They also have dictated alternate landing

locations in case of an undesirable launch.

One notable property of The Hybrid Model was an alternative path known as the "S-turn." This was a unique property designed to deal with high energy situations wherein the space shuttle would cross below 85,000 ft with a velocity much greater than Mach 2.5. In the Hybrid Model, this segment has many variations in design to account for various levels of supersonic flight and the associated turning limitations.

Rockwell followed through on their contract and delivered the first test shuttle (Enterprise) to NASA for testing in 1976. This unpowered vehicle would be tested in only approach and landing procedures. It would be flown into the air atop a B-747 and flown down to Edwards Air Force Base using various strategies to simulate the conditions the space shuttle would be subjected to upon landing. During testing in 1975, revelations about the effects of crosswind on the overall energy of the vehicle were assessed. They found that when the vehicle begins turning, the crosswind transitioning between a tailwind and headwind would cause a variation in the overall energy of the vehicle. Another criteria is that an ideal flight path be able to cope with some degree of wind conditions. It is important to deal with cross, tail, and head winds because they will affect the flight range and energy of the vehicle as it dynamically interacts with the air. During the landing procedures, ground teams will be analyzing weather patterns in order to predict various atmospheric properties at the time of landing. However, forecasting and now-casting meteorological techniques have limited accuracy when it comes to predicting wind speed and direction at high elevations. It is important to acknowledge weather conditions because nearly 75% of launches suffering delays or scrubs were due to failure to meet safety criteria. One of the two space shuttle crashes, the Challenger Explosion, was caused by meteorological conditions. Therefore, it is of high concern to NASA.

Reusable Launch Vehicles in the future will likely be terminal energy vehicles so managing the energy is a necessity, much like the space shuttle. These vehicles will need pre-planned guidance paths to land safely at a targeted point. Onboard guidance systems that are flexible when confronted by unplanned variances in the energy will be critical to ensuring a safe landing. The energy can vary based on the weight of the vehicle, the angle of decision, the cross winds, the initial speed, and numerous other variables. Several researchers have contributed to this overarching problem by developing algorithms that will be able to deal with many of the different variables that influence energy. Using different segments of geometry to achieve the maximum flexibility of the path has been the goal of many of the trajectories.

One notable model was developed by Cuciniello and his team for the Italian Aerospace Research Centre in Italy. It uses long-term and short-term trajectory generation. This two-trajectory approach allows them to use the long-term trajectory to align the vehicle with the runway through a series of turns while the short-term trajectory will be able to account for environmental disturbances. This uses optimization to solve for a path that will be able to adjust to different scenarios. These computations are complex and this will limit the number of short-term trajectories that can be generated limiting the overall flexibility of the vehicle.

III. Methods

Methodology

The present research was conducted using a design-based research approach blended with an experimental research approach. In order to design a new trajectory for the TAEM portion of the space shuttle landing sequence and the associated algorithm, new theories will need to be developed. The process needs to be flexible to account for unforeseen complications that arise due to physical world limitations. Previous experiments and data gathering flights conducted by NASA have yielded new data that will be used to steer the true trajectory of the shuttle when calculations are being conducted in real-time.

Design Frame-Work

The initial three-dimensional system of the flight path as the vehicle descends has been converted into a two-dimensional system referred to as the ground track system, as dictated by NASA. Our coordinate system will be established by placing the origin at the runway. Key landmarks are identified such as the initial condition point and the approach and landing points. It is important to remember that at each of these points the shuttle will have a specific speed, elevation and flight direction that must be taken into consideration when designing the flight path. When it comes to computing the values in a two dimensional ground track we must use new theories that are specific to the space shuttle. Kluever has simplified this problem for future research by developing a method of creating a table of values that can be fitted to a curve. This will allow the range-to-go measured on the ground track to be analyzed based on the total energy of the vehicle. This function can then be manipulated to find the velocity of the vehicle at any moment. The function does have its limitations, such as having a fixed glide efficiency factor, so determining a fixed angle of decline for the vehicle is also necessary. Choosing the ideal angle of decline is based on optimizing the maximum lift to drag ratio, and can be done for the vehicle prior to the flight. This allows the flight path algorithm to be less cumbersome on the computing abilities of the on-board computer and for alternative paths to be generated quicker based on changing conditions.

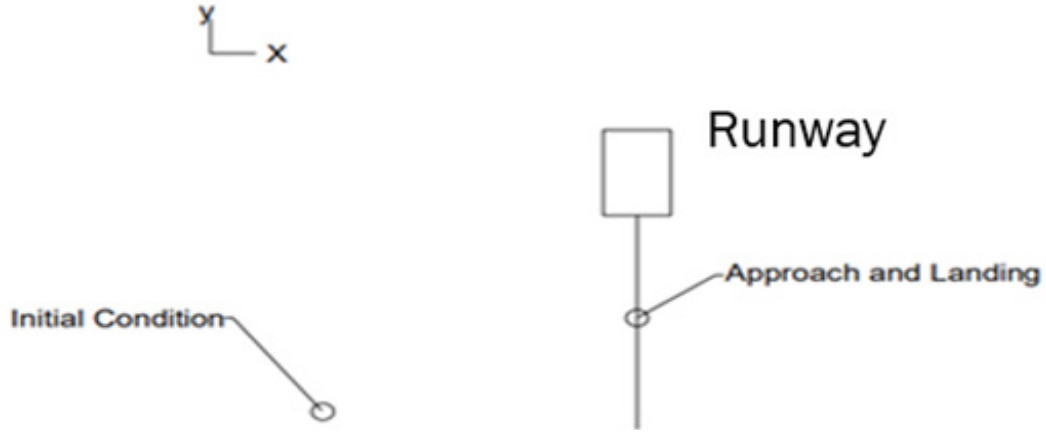

Figure 3. The two dimensional coordinate frame upon which the flight path will be constructed.

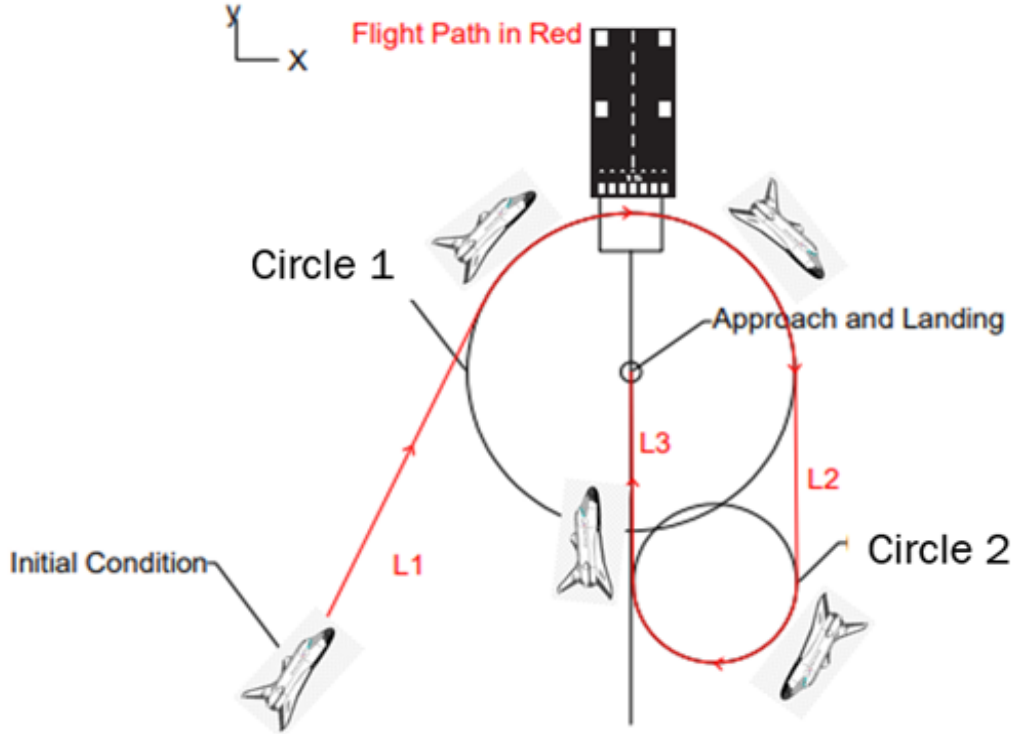

Figure 4. The two-circle concepts ground track with the flight path pictured in red.

Nomenclature

α	= Angle of Attack
ϕ	= Bank Angle
E	= Energy
Arch 1	= Flight Length around Circle 1
Arch 2	= Flight Length around Circle 2
L_2	= Flight Length from Circle 1 to Circle 2
L_3	= Flight Length from Circle 2 to Circle 1
L_1	= Flight Length of Tangent Line
ψ	= Heading Angle
AL	= Location Approach and Landing Point
IC	= Location of Initial Condition Point
TP	= Location of Tangent Point Between IC and Circle 1
Rgo	= Maximum Flight Range
R_1	= Radius of Circle 1
R_2	= Radius of Circle 2
ε	= Reciprocal of The Gliding Ratio
ΣR	= Total Distance of Flight Path
R_HAC	= Total Flight Distance From TP to AL
V	= Velocity
γ/2	= Y-axis Translation of Circle 2

Flight Path Development

The rough concept for the sketch of the design was adapted from Cuciniello's two circle approach with distinct changes to avoid optimization calculation sequence. Fixing the top circle (C_(1`)) with the center at the approach and landing points allows the radius to vary. A second circle (C_2) with no definite location but with a radius half that of C_1. The center location will translate along the y-axis but will not exceed the center of C_1. The flight path will fly the shuttle along segment L_1 ,between the Initial Condition and the tangent point. It will then travel the circumference for distance Arch 1 before departing at a point parallel to the center of C_1.

It will travel towards $C_2$for a variable distance, L_2, before departing to travel a semicircle, Arch 2, around Circle 2. Upon completion, it will fly up the approach and landing points along line L_3. At this point the shuttle should have acceptable roperties for the landing procedure.

Calculating Algorithm

The first step in the development of the algorithm is to find the maximum flight range (Rgo) of the Space Shuttle given the initial condition, location and properties. Rgo is calculated at the maximum energy at the initial condition point. The equation is derived below in equation (1).

$$E=V^2/(2*g)+h \quad (1)$$

From here the maximum energy E is related to the maximum flight range (Rgo). Using Kluever's line fit technique from the data, the graph was generated to relate the energy at any point during the shuttle's flight to its available flying range. We are able to formulate equation (2) from the graph pictured in Figure 5.

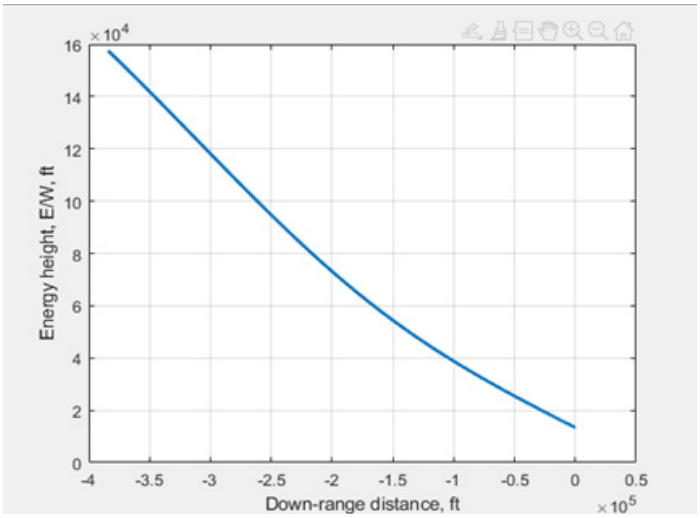

Figure 5. A plot of the change in E/W ratio for the flight range of the Space Shuttle.

$$R_{go}=E*2.547*e^{(0.3057*-3.59)}+-3.59*e^{(-1.933/(1/E))} \quad (2)$$

We can locate R_{go} by simply finding maximum Energy and its correlating available flight range. It is important to know this distance, R_{go}, because it is the maximum distance the shuttle can fly from the Initial Condition before it must be at the approach and landing points in order to land safely.

The second step is to establish a variable that is the total distance of the flight path (ΣR). this is done by summing our length segments L_1,Arch 1,L_2,Arch 2 and L_3. Calculating each value will also be required, but can be done using simple trigonometric and geometric properties. $L_1$is calculated using the distance formula derived from pythagoras theorem. The first point is the initial condition and the second is the tangent point along C1that allows the shuttle to fly clockwise.

$$L1=\sqrt{(x_{1c}-x_{TP})^2+(y_{lC}-y_{TP})^2} \quad (3)$$

Arch 1 is calculated using a variation of the circumference formula with the distance flown around the circle being calculated using dot product methods.

$$\text{Arch 1}=2*\pi*R_1*(\theta/360) \quad (4)$$

$L_2$and $L_3$are equal to each other and will be allowed to vary proportionally to Circle 2 location. Arch 2 is calculated using a similar method to Arch 1, but it will always be a semicircle allowing the formula to be simplified into:

$$\text{Arch 2}=\pi R_2 \quad (5)$$

It is important to note that $R_2$is always half that of $R_1$and will be calculated based on this value. The next step is conducted to find the radius of Circle 1. This computation is the most strenuous in terms of computing power and time. This is because during the flight the space shuttle makes turns like any aircraft: by rotating on its sides a certain amount. This rotating angle will be known as the bank angle (ϕ). We have elected to limit the bank angle around Circle 1 to 30 degrees to limit incidental energy loss during turning. Using the equation (6) we can begin to iterate for the radius of circle 1.

$$\phi_{bank}=\tan^{-1}(V^2/(R_1*g)) \quad (6)$$

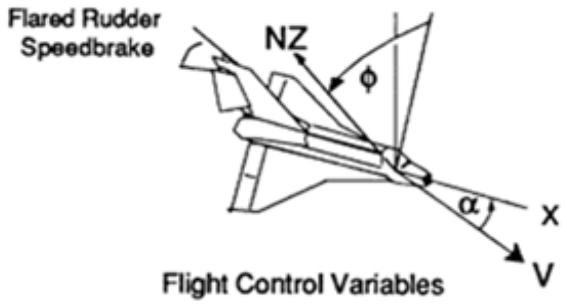

Figure 6. A model of the Space Shuttle showing the bank angle (ψ) and the angle of attack (α).

The last variable needed to begin iterating using equation (6) is the velocity at the point the Space Shuttle starts flying on Circle 1. To do this, we use well established models developed by previous researchers. This process is done by establishing an initial guess of what R_1that will be used to compute L_1. We then compte R_{HAC} using equation (7).

$$R_{HAC}=R_{go}-L1 \quad (7)$$

Using this value we manipulate our R_{go} equation (2) and compute the energy at that point. Using Kleuver's model again we are able to establish the velocity at that point, then use the bank angle equation to iterate a new value for R_1. This process is repeated until an ideal radius is chosen to ensure that the flight around that circle is both subsonic and that the radius large enough to ensure Arch 2 to be flown at an acceptable bank angle.

Once computed we can compute our γvalue for a specific flight path. γ/2 will be the distance that Circle 2 is translated along the y-axis from the point parallel to the center of Circle 1. This value will also be the length of segments $L_2$and L_3.

$$\gamma=R_{go}-(L_1+\text{Arch 1}+\text{Arch 2}) \quad (8)$$

Using the algorithm as our guidance system for our trajectory we can simulate results from the two-circle concept flight path. In addition, we can use these simulations to compare with other flight paths to ensure our flight path will meet the base requirements for any TAEM guidance system.

IV. Results and Conclusions

To run our simulation, initial condition properties were chosen to be similar to real world examples gathered from the previous 135 missions. Results were simulated using the algorithm described above in a MatLab to gather properties specific to the two-circle flight path. Simulations were done for initial conditions located in all 4 quadrants relative to the origin being the runway and results can be seen in Tables 1, 2,3, and 4 respectively.

Table 1. are the results calculated for an initial condition of (219500, 219410) located in Quadrant I.

Variable	Values	Units
Initial Condition Location from Origin	310356	ft
V_{1C}	2875	ft/s
ϕ_{bank}	29.92	Degrees
L_1	350822	ft
R_1	26252	ft
V_{TP}	606	ft/s
Arch 1	1941	ft
$\gamma/2=L_2=L_3$	19817	ft
Arch 2	41237	ft
V_{APL}	482	ft/s

Table 2 are the results calculated for an initial condition of (-245300,216510) located in Quadrant II.

Variable	Values	Units
Initial Condition Location from Origin	334718	ft
V_{1C}	2829	ft/s
ϕ_{bank}	29.97	Degrees
L_1	303502	ft
R_1	32033	ft
V_{TP}	669	ft/s
Arch 1	31056	ft
$\gamma/2=L_2=L_3$	24379	ft
Arch 2	50318	ft
V_{APL}	842	ft/s

Table 3 are the results calculated for an initial condition of (-248600,-224130) located in Quadrant III.

Variable	Values	Units
Initial Condition Location from Origin	327182	ft
V_{1C}	2960	ft/s
ϕ_{bank}	29.92	Degrees
L_1	365391	ft
R_1	26515	ft
V_{TP}	586	ft/s
Arch 1	3766	ft
$\gamma/2=L_2=L_3$	11414	ft
Arch 2	41469	ft
V_{APL}	482	ft/s

Table 4 shows the results calculated for an initial condition of (222150,-239410), located in Quadrant IV.

Variable	Values	Units
Initial Condition Location from Origin	326600	ft
V_{1C}	2760	ft/s
ϕ_{bank}	29.97	Degrees
L_1	291727	ft
R_1	31716	ft
V_{TP}	686	ft/s
Arch 1	30039	ft
$\gamma/2=L_2=L_3$	31024	ft
Arch 2	49819	ft
V_{APL}	482	ft/s

From studying the results generated for reasonable initial conditions there are some promising results. For starters we can determine that our initial condition assumptions were reasonable because they dictate an initial velocity for all quadrants that is around Mach 2.5 as NASA specified. The bank was successfully limited for in all simulations to be less than 30 degrees as elected. The length of segment L_1 ranges from 291,000 to 360,000 ft for the initial conditions and this distance consumes enough energy for the velocity at the tangent point to be subsonic, viewable in the V_{TP} values. When the space shuttle approaches from the North, the radius of the first circle iterates to be approximately 26,000 ft. When the space shuttle approaches from the South, the radius of the first circle iterates to be approximately 32,000 ft. Our γ and resultant L_2, L_3 values all vary proportionally on the initial condition - which they should, because they are determined by the initial condition

location. Lastly we can see that our approach and landing point velocity is 482 ft/s for all initial conditions, which is an acceptable velocity for the landing procedure to begin.

Using simulation results for the values given in Table 3, where the initial conditions are in Quadrant III, we can compare to those generated for alternate flight paths using established models and simulations.

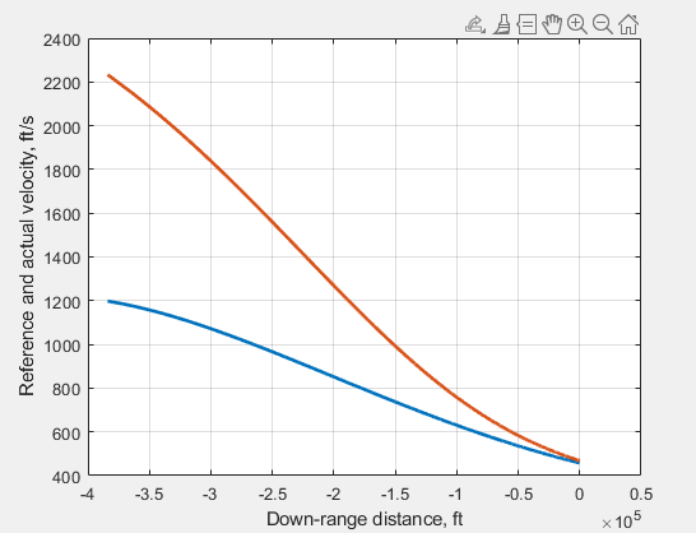

Figure 7. a graph of actual velocity during flight towards approach and landing point.

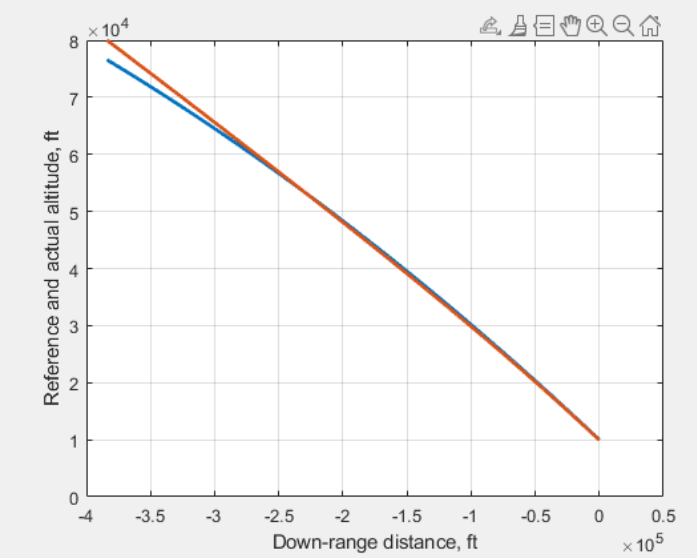

Figure 8. a plot of the altitude in orange as it flies towards approach and landing point.

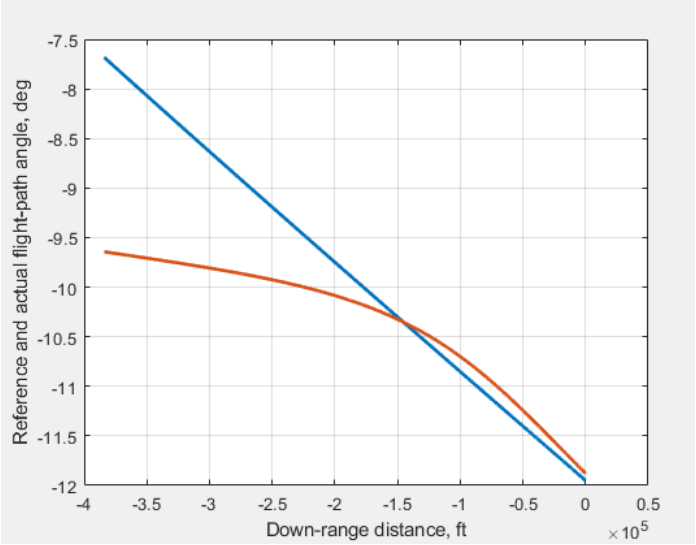

Figure 9. a plot of the angle of attack (α) in orange as it flies towards approach and landing point

Looking at Figure 7 we can see that the space shuttle along the two-circle concept flight path slows slower than an alternative flight path but will finish at an acceptable velocity of 482 ft per second. Looking at Figure 8 we can see that the Space Shuttle along the two-circle concept flight path decreases in altitude almost identically to other flight paths. That is confirmed by Figure 9 where we can see that the angle of attack is almost identical through the flight.

In conclusion the two-circle concept's primary advantage over the Cuciniello model is that its simplicity avoids mathematical optimization, so the on-board computer can conduct live simulations. Since the computations are done live we can adjust the computed energy value easily as tail, cross, or head effect it. This means that energy discrepancies are no problem for the two-circle concept to overcome. The two-circle concept's overhead approach is preferred by pilots when dealing with storms that often occur around the Cape Canaveral landing site. Another advantage is that the majority of the flight path is flown with no bank meaning that very little accidental energy loss will occur. It also has clear energy burning segments L2 and L3 that can also be modified in real time that highlight for future computational developments.

V. Summary

One clear limitation found in the flight path can be seen in the Acquisition Phase. For the two-circle concept flight path we assumed that the initial condition heading angle (ψ_{1C}) was equal to tangent line heading angle (ψ_{TL}). This would not be the case in real world applications turning to that heading angle is required. When designing this program it became clear that when ψ_{1C} deviated ±60 degrees from the ψ_{TL} it would require too much ground

track distance to turn. This is due to bank angle and resultant radius constraints; the turning path's distance would be too large to also make it to the approach and landing point at the desired energy level. To deal with this problem, one viable solution would be to design an additional portion of the algorithm to enable the storage of kinetic energy (velocity) as potential energy (increasing altitude). Slowing the vehicle allows the turning radius to be smaller. Therefore, the ground track consumption during the Acquisition Phase would be within an acceptable range. This stored energy would increase E and can later be consumed by increasing the γ distance, modifying the resultant Circle 2 position, $L_2$and L_3distances. This will have rippling effects on our algorithm, but all quantities and properties needed to adjust for this change are already present.

VI. Acknowledgements

I want to begin by thanking the McNair Scholars Program and the Mizzou McNair staff for funding my research and giving me numerous resources along the way. I want to thank my advisor and mentor Dr. Craig Kluever for bringing me this project and guiding me throughout this process, without his aid and expertise none of this would have been possible. I want to thank NASA and other previous researchers for laying the ground which this research stands on.

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Featured Scholar

Paulos Mengsteab, PhD
IChan School of Medicine at Mount Sinai
MD Class of 2023
2012-2013 MU McNair Scholar
PhD in Biomdeical Engiineering, University of Connecticut in 2019

The McNair Scholars Program was a formative experience in my academic journey. I still remember the day that I received an email advertisement from the Mizzou McNair Scholars Program for an informational session on the goals and structure of the program. I must admit that the stipend certainly caught my eye as a student working at both the library and a restaurat throughout my first two years at Mizzou. The idea of being paid to undertake an academic endeavor was foreign to me.

"Why do you want to become a biomedical engineer instead of a doctor?" asked Dr. Davis and Mr. Bloss during my interview. A great question that left me saying, "I want to provide doctors the tools that they do not already have." I was inspired to pursue a Ph.D. in biomedical engineering due to my sports injuries and three anterior cruciate ligament (ACL) tears in 1.5 years. That experience begged me to ask, why did this occur? Even with that curiosity, it was not until I became a member of McNair that I became equipped with the tools needed to become a successful researcher and tackle such questions.

While a McNair Scholar, I was fortunate to work on an orthopedic-related project under Dr. Ahmed Sherif El-Gizawy in the Department of Mechanical Engineering. Under his guidance and Laurent Eap's, my graduate student mentor, I learned the scientific method. This research experience provided me with what I missed most in my first three years at Mizzou, applying classroom knowledge. As the year went on, it became apparent that my calling was to become a scientist.

In addition to the in-lab experience, the McNair Scholars Program provided a robust research curriculum to equip us with the tools of a researcher. We learned how to perform a literature search, write a manuscript, prepare posters for a conference, and practice our presentation skills. Furthermore, we were exposed to the various scholarship opportunities for graduate school and pipeline programs designed to increase our competitiveness for graduate school. I also look back fondly on the dining etiquette class we took!

With the guidance of McNair, I was fortunate to be selected for the PREP at the University of Washington in Seattle. There I continued to build on my skills as a scientist under the mentorship of Dr. Deok-Ho Kim and had the opportunity to collaborate with international scientists from the National Institute of Materials Science in Tsukuba, Japan.

In 2019, I received my Ph.D. in Biomedical Engineering at the University of Connecticut, under Dr. Cato T. Laurencin, where I researched the regeneration potential of biodegradable ACL matrices for ACL reconstruction. Things indeed came full circle from those previous ACL injuries I had! Subsequently, I decided to pursue my MD. I am currently a third-year medical student at the Icahn School of Medicine at Mount Sinai – I guess I could never shake the question that Natasha and Jeremy previously posed to me, "why, not a doctor?"

What can I say besides how great the McNair program was for me! Indeed, there was a lot of hard work along the path to gaining my Ph.D. and entering medical school. Still, I believe it would not have been possible without the McNair Scholars Program exposing me to research as well as instructing me on the fundamentals of the scientific method. This program was the inception of my academic career as a biomedical researcher and now an aspiring physician. TRIO certainly works! I wish all the luck to the current and past McNair scholars at Mizzou and beyond!

2020-2021 Research Topics

Scholar	Major	Title	Mentor
Stephan Agee	Mechanical Engineering	The Effect of Nanoparticles on Thermal Properties of Sodium Acetate Trihydrate Phase Change Material	Hongbin Ma
Angelique Allen	Biological Sciences	Problem-solving Abilities and Survival Rates in *Anolis sagre*i	Manuel Leal
Elias Bunting	Natural Resources	Assessment of genetic variation for economic traits among eastern black walnut (*Juglans nigra*) cultivars	Alba Argerich
Kelly Dade	Electrical Engineering	Radar Sensors Role in Understanding Greenland Ice Sheet Contributions to Sea Level	Justin Legarsky
Kyles Downes	Mechanical & Aerospace Engineering	Terminal Area Energy Management of the Space Shuttle	Craig Kluever
Chavis Ferguson	Biomedical Engineering	Chemical Composition Affects Physical Attributes and Biocompatibility of Hydrogels for Spinal Fracture Repair	Bretty Ulery
Derek Fiquet	Interdisciplinary Studies (Enviromental Sciences)	Exploring Global Threats in the Stream Ecosystems of the Ozark National Science Riverways and James River Watersheds	Thomas Bonnot
Ja'Vion Golden	Health Sciences	Biomarkers of Erythrocyte Senescence	Kuanysh Kabytaev
Christian Kinghorne	Psychology	Will *You* Wear a Mask? A Study of Compliance to Mandatory and Voluntary Covid-19 Health Measures	Chunyan Peng
Adam Lappe	Political Science	Triggers of Jurisdiction and the International Criminal Court	Bryce Reeder
Marshaun Love	Biological Sciences	Cardiac stiffness and left-atrial stretch of the young and aged myocardium	
Abdul Habib Omar	Biochemistry and Biologicial Sciences	Multiple micronutrient fortification -	
Ymbar Polanco Pino	Mechanical & Aerospace Engineering	Experimental investigation of using inverted thin-film plates for energy harvest	Sheng Wang
Tessi Rickabaugh	Women's & Gender Studies and Religious Studies	The Space Between: Purity Culture as a Liminal Time	Francisco Sanchez
Francesca Rodriguez-Hart	Geography	New Urbanism at Middle Ages: Community Attachement, Place Attachment, and Opportunities and Limitations of Top-Down Community Making	Matthew Foulkes
Claire Schneider	Architectual Studies	After the Lawns are Gone: Mending a Gap Between Theory and Practice	Robert Walsh
Caleb Sewell	Educational Studies and Black Studies	The Value Gap in Higher Education	Stephen Graves
Katherine Thomas	Human Development and Family Sciences	Grief, Bereavement, and Grandparent Death Loss: Lived Experiences from Black Female Perspectives in College	Tashel Bordere
Mason Ward	Plant Sciences	Descriptions of the Nymphal Instars of *Gestroiella siamensis* Polhemus, Polhumus and Sites (Hempitera: Heteroptera: Naucoridae) and Phoretic Association with *Nanocladius* Kieffer (Diptera: Chironomidae)	Robert Sites
Yuki Yang	Biological Sciences	Enhancing Myovascular Regneration with a Novel Biomaterial Following Traumatic Muscle Loss	Steven Segal and Aaron Morton

2020-2021 McNair Scholars

Group Photo from 2021 McNair Scholars Conference

Top Row: Claire Schneider, Angelique Allen, Tessi Muskrat Rickabaugh, Stephan Agee Habib Omar

Second Row: Derek Fiquet, Jay Golden, Adam Lappe, Yuki Yang, Kyle Downes

Third Row: Francesca Rodriguez-Hart, Kelly Dade, Elias Bunting, Christian Kinghorne, Caleb Sewell

Fourth Row: Ymbar Polanco Pino, Chavis Ferguson

Bottom Row: Natalie Downer (Associate Director), Jeremy Bloss (Program Coordinator), James Hamilton (Program Assistant)

Not Pictured: Mason Ward, Marshaun Love, Katherine Thomas, NaTashua Davis (Program Director)

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